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Soil resources and land use in south-western Australia

Presidential Address 1980

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Abstract

Field studies of soils and their distribution in Australia generally, and in south-western Australia in particular, are briefly reviewed, and the influence of similar studies in Russia and the United States of America indicated. The significance of field studies of soils in south-western Australia is discussed in relation to the assessment of soil resources for land-use planning. In this context, the argument is advanced that the landscape as a whole, together with the biological and physical processes taking place within it, is a more useful frame of reference than the traditional soil profile only a metre or two deep. Land-use planning in south-western Australia, in regard to forestry, farming and water supply, is considered. The conclusion is reached that the benefits of increased knowledge and understanding of soils and other environmental factors are unlikely to be fully realised in the absence of an effective regional planning machinery.

Introduction

I am concerned, in this address, mainly with field studies of soils in Western Australia, as they relate to land use; i.e. with the implications of soil distribution and characteristics for land-use planning and management. I shall not be dealing with, for example, specific studies of plant and animal nutrition related to trace element and other nutritional deficiencies, where pioneer workers like L. J. H. Teakle, T. C. Dunne and E. J. Underwood have made such substantial contributions. Nor shall I be considering the important studies of the fundamental physical chemistry of soils and minerals of A. M. Posner, F. J. Hingston, J. P. Quirk and others. Instead, my subject is the landforms and soils mainly of south-western Australia, and some of the soil and landscape properties and processes relevant to our use of the land. A principal objective of such studies is, of course, a contribution to the technical basis of rational use of the land through the understanding and assessment of soil resources.

Assessment of soil resources

The assessment of Australia's soil resources began with the early explorations, and they were often highly optimistic. We may contrast Captain Stirling's reports on the agricultural potential of the proposed Swan River Colony with the subsequent difficulties encountered in establishing a viable agriculture: or, in more recent times, there are the hardships and miseries suffered by the group settlers in the South-West, whose story has been told so well by Geoffrey Bolton in "A Fine Country to Starve In" (Bolton 1972). The optimism was often due to ignorance of technical problems, many of which we now recognise. So it is not surprising that, as a more scientific and technical approach developed, soil scientists did not always share the enthusiasms of their governments. Many of you will remember the late L. J. H. Teakle, whose assessment of the risks of soil salinity in a large area of virgin land south of Southern Cross led to the ambitious "3500 Farms Scheme" being dropped in the 1930s (Teakle 1939). That experience, which we are well placed to appreciate in the light of today's problems, emphasises the need for systematic and objective assessment of our soil and land resources.

I do not, of course, mean to suggest that an assessment of soil and land resources ought to be the sole determinant of decisions with regard to agricultural and other developments. Clearly, social, economic and political factors are also involved. But they should not be allowed to obscure the technical difficulties which may be inherent in the nature of the resources themselves.

Overseas examples

The development of scientifically based studies leading to assessment of Australia's soil resources was, of course, influenced by experience elsewhere, particularly in Russia and the United States of America.

The Russian experience

Soil scientists are familiar with the principles developed by Dokuchaev (1883) and his colleagues in Russia about the middle of last century. They included the concept of Great Soil Groups and their distribution over the land mass of European Russia according to climatically defined zones. Terms like podsol, brown forest soil, black soil and solonetz became widely known and used in many countries beyond Russia. What is not so widely appreciated is that the work of Dokuchaev and his colleagues was

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in response to a need for an exploratory assessment of land resources and their potential productivity over a vast continent. Because of the practical difficulty of effective observation over large areas, the philosophy of the approach was prediction of soil conditions on the basis of known or assumed relationships with environmental factors, particularly climate. There must have been a degree of success, since the Russians were confident enough to go further and produce, between wars, a soil map of the world, based on those relationships. While it was a valiant effort, it has serious defects, particularly in respect to Australian soils, which, as I shall discuss later, are much more conditioned by past climates than those of the present.

The Russian scientists showed that the forest soils of the northern cool temperate zones, with abundant rainfall, formed over glacial or periglacial deposits with an abundance of fresh minerals. Thus they had an inherent capacity to replenish losses caused by productive use of the soil as those minerals weathered. They are subject to leaching losses of bases and nutrients, and waterlogging, so that liming, fertilisation and drainage are the main ameliorative measures required.

The soils of the drier, warmer grasslands, e.g. the black soils of the Ukraine, with a similar mineral-rich substrate, but less subject to leaching, had high natural fertility and a more readily sustained productivity. Expansion of agriculture on such soils, as they extend into lower rainfall country on the Siberian Plains beyond the Ural Mountains, is still in progress. A rather mystical or sentimental faith in the inherent productivity of the Russian chernozem or black soil was responsible for delays in developing the fertilizer technology necessary for the higher levels of production which are possible.

In the humid tropics the Russians predicted deep weathering and deficient mineral substrates, with short-lived high initial fertility in the surface organic layers built up by the indigenous forests, and a lower capacity to restore the losses through further mineral weathering. They recognised salinity problems in semi-arid and arid areas.

Such a conceptual framework rationalises the history of agricultural development. The northern forest lands and the drier and warmer grasslands became the permanent farmlands of Europe and eventually the United States. The earlier intensification of agriculture in the dry Middle East and wet tropical Asia depended on the alluvial plains of the great river systems such as the Nile or the Ganges. Their flood waters, loaded with sediments, both replenish fertility and make irrigation possible, provided that an appropriate technology can be developed and maintained.

The Russian approach, brought to Australia by J. A. Prescott, was the basis of the first soil map of Australia, published with his bulletin "The soils of Australia in relation to vegetation and climate" (Prescott 1931). It was an important and most useful compilation in its day. The difficulties overcome in gathering the information must have been formidable, in the absence of today's rapid and easy transport, with few reliable maps or air photographs and no such thing as satellite imagery. Prescott's map was the beginning of many attempts to systematise the information being gathered piecemeal throughout the continent by land surveyors, government chemists and the like, and stimulated Teakle's early soil classification work in Western Australia and the many soil surveys under his direction (Teakle 1938).

The United States experience

At about the same period, the American situation resembled the Russian in that there was a need for an exploratory assessment of soil resources. While surveys began with simple attempts to classify soils on the basis of the geology of parent materials and the assessment of fertility by chemical analysis for nutrient elements, the Americans too were later influenced by the Russian concepts. Again, the particular appeal of these concepts lay in soil-environmental factor relationships as a basis for understanding and predicting soil characteristics over large areas (Marbut 1927). However, there remained, as well, a preoccupation with detail, often unguided by principle, whether scientific or use-orientated. Faith in a technology fueled by abundant cheap energy, and a lack of appreciation of the need to protect the complex soil biological systems led to severe erosion problems prior to the establishment of the United States Soil Conservation Service. This experience too has had its influence on the Australian approach.

Australian conditions

There are some important differences between Australian conditions and those in Europe and North America from which example and experience could be drawn. There the new areas being explored and developed were characterised by soils which were often naturally highly productive, and many other environmental factors were similar to those in the longer settled European areas from which the pioneering effort came.

In Australia the conditions were, and are, vastly different, particularly I would suggest in respect of geological history, superficial geology and consequently the soil parent materials. In Australia, the superficial deposits and deep-weathered profiles are quite unlike those of the countries from which the settlers came. This is especially so in Western Australia, where the Precambrian Shield is relatively unaffected by earth movements that have affected other parts of the world, including eastern Australia. It has thus, to a great extent, not been subjected to the erosional and depositional processes brought about elsewhere, which have destroyed older landscape elements and their associated weathering products and soils (Mulcahy 1961). The Permian and younger sediments, representing the shallow seas which once separated Western Australia from the rest of the continent, lie relatively undisturbed beneath the deserts that still separate us almost as effectively.

In other words, the landscape is a very old one. Johnstone *et al.* (1973) suggest that its main form in south-western Australia, with a drainage system "whose relics are the chains of salt lakes seen today", was established by the late Jurassic to early Cretaceous. If this is true, then it has survived since before the Gondwanaland continents drifted apart, and during the earth movements which formed the Alps and the Rocky Mountains. Much later it escaped the more drastic effects of the ice ages which in Europe

and America ground away the old soils, and laid down fresh materials on which new and more fertile soils could form.

In another important respect, conditions in Australia are also very different. In Europe and North America, where there are many more and longer established research institutions, soil scientists are well served in respect of knowledge of the superficial geology from the work of Pleistocene stratigraphers, geomorphologists and geologists. Here in Australia we are not so well aware of the nature, let alone the extent, of the superficial deposits and weathered mantles which form the soil parent material, and the soil scientist has had to undertake their investigation for himself. Some interesting work has been done as a consequence, which I cannot review here, but have discussed elsewhere (Mulcahy and Churchward 1973).

Soils of south-western Australia

Soils with such a long history as those of south-western Australia must have experienced a wide range of climatic conditions, and consequently a close correlation between soil and present day climatic zones would not be expected. Indeed, extremely weathered profiles and leached soils normally associated with the humid tropics are widespread in Western Australia generally, extending far beyond the present high rainfall areas into the semi-arid and arid regions. They are generally of low fertility, due to deficiencies of nutrient elements, both major and minor. Applied nutrients, particularly phosphorus, may be fixed in forms unavailable to plants, or alternatively, lost by leaching from the coarse-textured surface sands. These soil properties are characteristic of tropical and arid areas of many of the underdeveloped countries.

The old soils of south-western Australia, inherited from past periods in geological time, have not survived completely unchanged until the present day, though they do carry the marks of their history. Perhaps I can best illustrate this and at the same time give some indication of advances in knowledge over the last forty or fifty years by a comparison of Prescott's 1931 soil map of Australia, with the more recent atlas of Australian soils (Northcote *et al.* 1967), a simplified form of which has been produced by Mulcahy (1973).

While Prescott's map recognised the great extent of the leached lateritic soils in the drier areas, and referred to them as "fossil" soils markedly influenced by past climates which were warmer and more humid, his map nevertheless shows the influence of the Russian approach in that his boundaries tend to align themselves with the boundaries of climatic zones. In contrast, the later map, based on more detailed information, shows superimposed on this a relationship between soil distribution and the drainage system. It reflects also the modifications of the old landscapes by the processes of subaerial erosion and deposition which have acted over time to produce a complex landscape and soil pattern, the main features of which are:

(1) The salt lake chains of the interior clearly have a riverine form, draining both westwards to the coast, and eastwards to terminate in the shallow marine sediments of the Nullarbor Plain. These are the relict drainage systems already referred to, and shown in Figure 1.

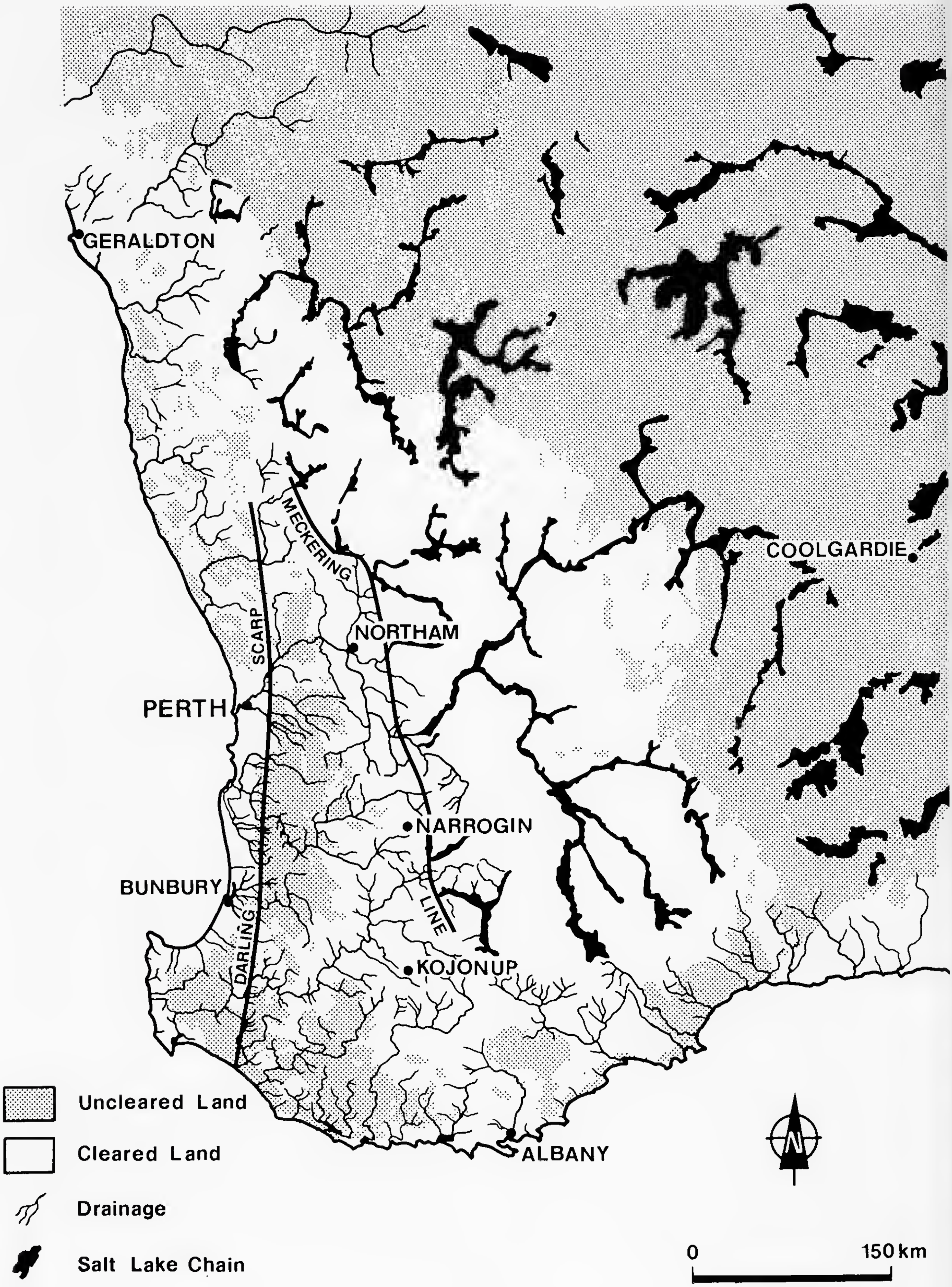
(2) The now sluggish and ineffectual drainage system represented by the salt lake chains ceases abruptly in the west along the Meckering Line (Fig. 1), named after the town through which it passes. Downstream of that line, there is a closer, more incised and effective network of streams. This change in land form bears a fascinating geographic relationship to the zone of seismic activity associated with the Yandanooka-Cape Riche lineament (Everingham 1968) running along the line of the Avon Valley and the Great Southern railway line, a little to the west. This raises the suggestion, which is of course not new (Penck 1953), that the nature of the landforms, and in this case also the distribution of the soils, reflects the tectonic history of the continental margin. It seems that only in the limited areas where there has been tectonic activity has the landscape sufficient relief to enable erosional processes, acting over geological time, to create new surfaces of any significant though limited extent. Here too are the limited areas of naturally fertile soils which were the basis of the State's earliest agricultural development.

(3) The source of the salts accumulating in the landscape, most obviously in the salt lakes, is as a dilute solution in the water falling as rain. Nevertheless the amounts received are large, ranging from 150 kg/ha. yr, mainly NaCl, near the coast to 30 kg/ha. yr in the interior (Hingston and Gailitis 1976). Only about 10% is found in the salt lakes, the remainder, amounting to 10^6 kg/ha or more, is in the deep subsoils (Dimmock *et al.* 1974).

(4) Lateritic sandplain soils are extensive inland of the Meckering line, and both they and the valleys of the salt lake chains are underlain by very deep (30 m or more) zones of extremely weathered sandy clays, often called 'pallid zone' because of their pale colour. It is in this part of the profile that much of the salt accumulates. The surface sands are deficient in N and P, and also the trace elements Cu, Zn and Mo. They may also fix much of the phosphate applied as fertiliser in unavailable forms. Thus agricultural development was impossible on them until the problems were understood and suitable fertiliser technology developed.

(5) The western and south-western areas are dominated by lateritic ironstone gravel soils, often bauxitic, typically in the Darling Range. They also are underlain by deep pallid zones, but here, especially in the higher rainfall areas nearer the coast, salt storage is lower, despite the higher input, due to more effective leaching. The soils share the nutritional problems of the sand plains. This, and high clearing costs due to heavy timber, prevented early clearing for agriculture thus fortunately preserving the forests with their role in protecting the water resources.

(6) The surface soils of the sandplains and bauxites transmit water rapidly, due to their coarse textures. The underlying clays of the pallid zones tend to have low transmissivities (Hurle and Johnston 1979), except where formed over more sandy parent rocks such as the Permian sediments of the Collie coal basin. In the latter case, levels of salt storage in the profile tend to be lower.


GERALDTON
MECKERING
NORTHAM
SCARP
PERTH
NARROGIN
BUNBURY
DARLING
LINE
KOJONUP
ALBANY
COOLGARDIE
Uncleared Land
Cleared Land
Drainage
Salt Lake Chain
N
0
150 km
SCALE

(7) Between the extensive sandplain areas and the lateritic or bauxitic ironstone gravel soils, is a zone of incised and effective drainage, where the lateritic sands and gravels crown the divides and spurs; exposed pallid zone and other preweathered material lies on the slopes below, and fresh rock as a soil parent material is occasionally exposed in the more deeply and sharply incised valleys.

(8) Widespread removal of the lateritic materials to give younger, more fertile soils is thus found only in more incised valleys, such as that of the Avon near York and Northam, or the Blackwood at Bridgetown.

(9) Fine-textured, silty, saline and calcareous soils appear to be associated with the salt-lake chains, and are believed to be, at least in part, due to wind action, which has blown loess-like materials with these characteristics from the lake floors when dry, to blanket country downwind, generally to the east and south-east of the postulated source (Bettenay 1962). Killigrew and Glassford (1976) suggest that kaolin spherites in sand plain deposits are also aeolian in origin, from a source in fluviatile sediments.

In summary, then, due to its history, the landscape is characterised by a great extent of extremely weathered materials, which may, in some cases, have been transported some distance from their source. The soils developed on them are of low fertility—the sandplains, laterites, and bauxites—and hence of low biological productivity in their natural state. They have, due to their great depth, a great capacity to store water. The extreme and deep weathering indicates the loss of much of the original mineral constituents and their movement out of the landscape through a drainage system which, in the past, must have been more effective than it is today. It also indicates that the accumulations of soluble salts now found deep in the soils must have taken place following the weathering, which required effective leaching and removal of such soluble materials. At present day rates of accession, the salts could have accumulated in a relatively short period, say, a few tens of thousands of years (Dimock *et al.* 1974).

Soils and land use

Until 150 years ago, south-western Australia was occupied by Aborigines whose systems of land use were adapted to the low levels of biological productivity resulting from the nature of the soils. Thus their levels of consumption were also necessarily low, since there was little external trade, and little opportunity to import. The ways in which they took their living from the land were, nevertheless, in a stable equilibrium with their environment, as shown by the survival of aboriginal cultures for many thousands of years. Even so, in reaching such a state they may well have been a substantial modifying factor. Indeed, Dr. Merrilees entitled his Presidential Address to this Society in 1967 "Man the Destroyer", since he believed them to have contributed to the extinction of a number of species now known to us only through their fossil remains (Merrilees 1968). European settlement brought an end to isolation, and introduced a society with expectations of higher levels of consumption, and a much greater ability to modify the natural environment, and to extract and produce from it. There followed the development of an agricultural technology dependent on the restoration of the soil fertility lost through long continued weathering by imports of fertiliser, and through the introduction of legumes compatible with European style agriculture. The rate of agricultural development and its productivity was later increased by the availability of machinery and the fuel to drive it. Discovery of gold and other minerals, and the export of timber, supported the economy in the meantime. Now income derived from such forms of primary production supports an affluent and consumer orientated society, generates capital, and attracts secondary industry.

Figure 1.—Drainage systems of south-western Australia.

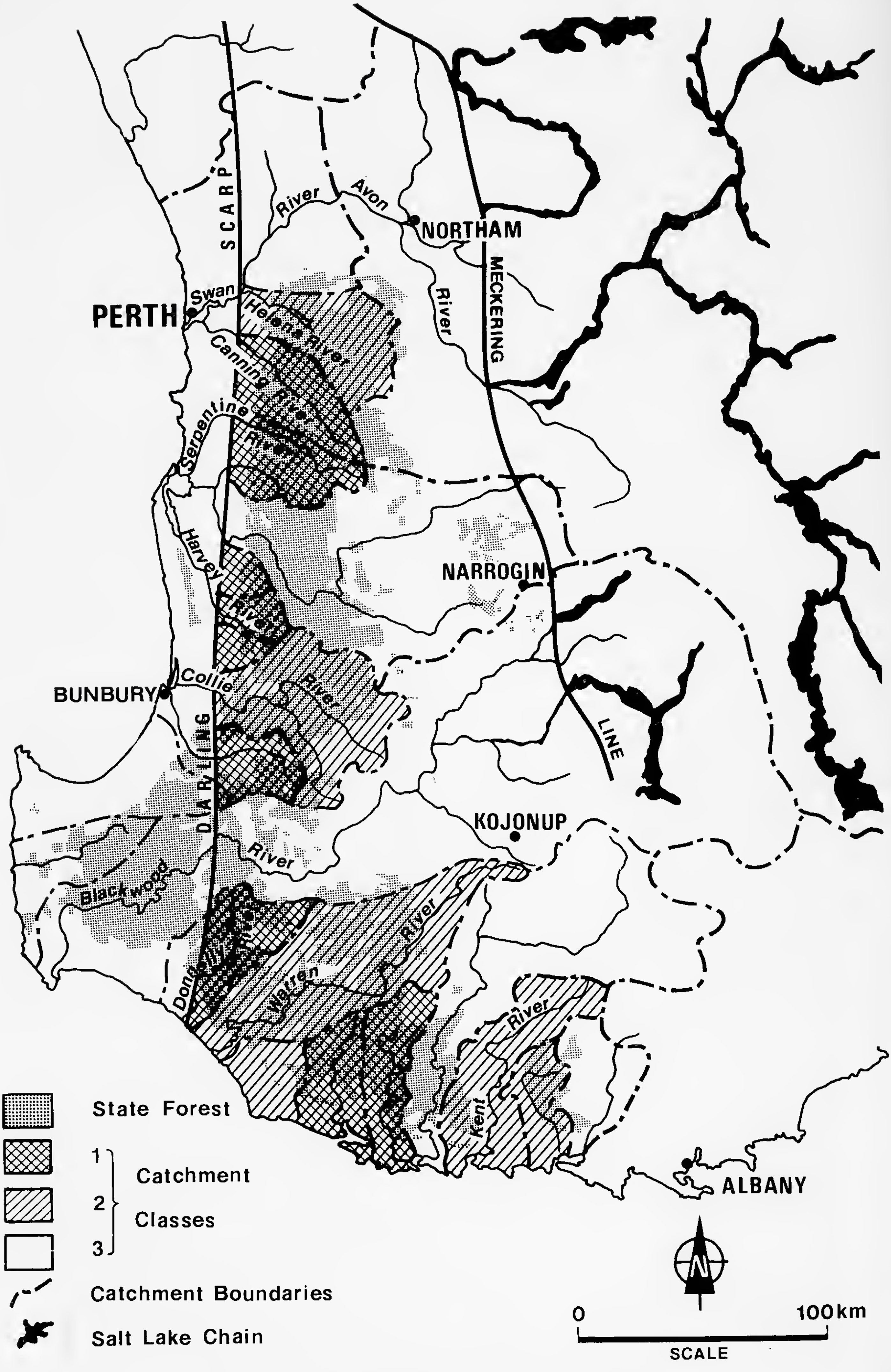
The impact of these developments on the land resources is, of course, considerable. We are still seeking a new, stable balance between these increased levels of human activity, and the natural environment, which must minimise irreversible adverse effects if our society is to survive in the long term. It can hardly be argued that this has yet been achieved, in view of the disturbed salt and water balances of agricultural areas and catchments, the declining productivity of pastoral areas, the unhealthy condition of much of the jarrah forest, and the paucity of conservation reserves, particularly in the wheatbelt. Let me briefly mention some of the principal problems of our main rural land uses, forestry, agriculture and water supply.

Forestry

The native hardwood forests of the South-West are uniquely adapted to their peculiar environment, in ways which research workers and forest managers are just beginning to understand. These mechanisms enable the forests to grow on the extremely deficient soils and survive the rainless summers. Substantial areas have been lost to agriculture, others to urban, residential and industrial development, and the full impact of open-cut mining is yet to be determined. Protection of water resources and the use of forest areas for public recreation are now recognised as having as high a priority as wood production, and good management could increase the potential values of both.

Most of the forest area has been cut over at least once, and some of it successfully regenerated, but it is threatened by disease, and the risks are heightened by all these increased levels of human activity. It is likely that the demands for wood products will rapidly increase in the future, in fact the demand for increased production is probably already here. Woodchips are exported from the karri areas, and increases in energy costs, together with improvements in harvesting technology are likely to put further pressure on the jarrah forest for wood and other products for fuel. Intensification of production and export of nutrients may be expected to involve risks of long-term loss of biological productivity of ecosystems growing on such extremely deficient mineral substrates.

These developments can be seen either as a threat, or as an opportunity. I prefer the latter alternative. Provided that adequate conservation areas are established, the income derived, or anticipated, from increased production of commercial value of both



PERTH
NORTHAM
NARROGIN
BUNBURY
KOJONUP
ALBANY
SCARP
DARLING
MECKERING
LINE
Swan
Avon
River
Helena River
Canning River
Serpentine River
Harvey River
Collie River
Blackwood River
Donnelly River
Warren River
Kent River
State Forest
1
2
3
Catchment
Classes
Catchment Boundaries
Salt Lake Chain
N
0
100km
SCALE

wood and water could provide the funds for the intensification of management which will be necessary if the forest is to be maintained and protected.

But such management will depend on predictions based on understanding, consequently research on the functioning of the forest ecosystem assumes a high priority.

Agriculture

Agriculture has been one of Western Australia's success stories, culminating in the late sixties with "a million acres of new farms a year". The scientific work in support of agricultural development has been purposeful and effective, though unfortunately I cannot review it here. Yet there are still the adverse effects of salinisation of soils and water supplies, due to the failure of our present agricultural systems to use soil water as fully as did the native plant communities which they replace. (Mulcahy 1978). While there is considerable interest, and a great deal of experimental work on the effects of reafforestation, screening of suitable tree species for the purpose, and on revegetation of saline soils, so far I do not believe that a purposeful effort is being made to modify agriculture in ways that will use the water where it falls, so that catchment salt and water balances may be restored and adverse effects on water resources and soils avoided. The present array of agricultural plants results from 150 years of introduction, selection and breeding, with the objective of producing crops and pastures which can complete their cycle of germination, growth, flowering, and seed setting before the moisture available in the surface soil is exhausted. Thus the risk of failure to complete the growth cycle in a dry season is minimised, an obvious advantage to the farmer. Long-term research on agricultural systems should now aim at finding agricultural plants, perhaps perennials, which would use more water from greater depths. Increased water consumption by as little as 10% might suffice, but this must be at the cost of greater risk of failure in a low rainfall season, though it might be offset by a greater potential for production in good seasons.

Water Supply.

That water supply can be affected by other land-use practices is clear from what I have already said. The phenomena outlined are the basis for a classification of catchments and the discussion of their management (Sadler and Williams 1979). Essentially it depends on the extent of a catchment beyond State Forest, or inland of the 800 mm isohyet, into predominantly agricultural land and on whether the headwaters tap the inland salt lake systems.

Three groups of catchments may then be identified (Fig. 2):

Class 1 catchments are those of rivers rising almost completely within forest areas. Water yield is high, quality good; several rivers are already harnessed for water supply and others are likely to be in future.

Figure 2.—Surface water catchments in south-western Australia. See text for explanation of catchment classes.

Class 2 catchments are those of rivers which extend beyond the forest into agricultural land in their headwaters, but do not tap the salt lake systems. Yields are still high, but quality has been affected by clearing. Several are dammed, and the others may be developed in the future.

Class 3 catchments are the most extensive, between them draining about two-thirds of the agricultural areas. Several of them, notably the Swan-Avon and the Blackwood, tap the salt lake systems (Fig. 2) which have been known to flow as an entire system in exceptionally wet years. Their yield is high but is generally of poor quality, being either brackish or saline. It should be noted, however, that certain of their downstream tributaries could well qualify for Class 2, and a few for Class 1.

Of the three classes, only 1 and 2 are seriously considered for water supply development. Of the two, those in class 1 are clearly the most valuable on grounds of both yield and quality. In general, land use is strictly controlled on them, since they lie mainly within State Forest, where management policies give high priority to conservation of the water resource. Bauxite mining is in progress there with removal of the permeable surface soil bringing the less permeable subsoil clays much closer to the new land surface. This can lead to downstream effects on wetlands and on stream courses due to changes in catchment characteristics. It can result in more rapid and frequent run-off events of shorter duration, and an increased risk of salinisation in lower rainfall areas.

The class 2 catchments are the really pressing management problem, so much so, that the State has very recently moved to establish controls on the clearing of privately owned land within them, with the principal objective of preventing further clearing in the lower rainfall parts. There are significant areas of as yet uncleared land on many farms in these lower rainfall head-water areas, which, if developed for agriculture, would lead to further deterioration in water quality. The controls, which involve compensation payments, are administered in accordance with guidelines which reflect the variation and interaction of the soil, rainfall and other factors, and their effects on the subsurface hydrology.

Discussion

Traditionally, soil science concerns itself with the soil profile, usually only a metre or two in depth, its characteristics and the processes going on within it. Yet it would seem that the land-use problems discussed here call for more than this, involving the characteristics and processes of the landscape as a whole.

For general purposes a study of functional relationships within the landscape rather than just within the soil profile is required. It will be particularly important in respect of the movement of water and solutes in the superficial deposits and weathered profiles which in many cases form shallow aquifiers, and in which soluble salts are stored. These hydrologic systems can be readily modified by agricultural and

other land uses (Bettenay *et al.* 1964). Kovda *et al.* (1968) show the importance of such relationships and their changes over time in investigations or regional geochemistry, with potential application in mineral exploration. They are fundamental to the interpretation of studies of forested catchments, whether they are concerned with the effects of management on nutrient losses and long term productivity (e.g. Bormann *et al.* 1974), or on water yield and quality (Shea *et al.* 1975). Such functional relationships in landscapes have long been part of the thinking of some soil scientists like Milne (1947) and Glentworth and Dion (1949), though they too were mainly concerned with the surface soil profile. But the surface soil is only part of the natural system to be managed. Flows of water, nutrients and energy are likely to be more usefully studied in the frame of reference of the landscape and the ecosystem; geochemical and mineralogical differentiation takes place, not only in the surface soil but in the landscape as a whole.

Conclusion

Underlying what I have said in discussing the land use problems of south-western Australia, is the clear implication that growth and development is forcing the State of Western Australia towards a situation in which there is an increasing degree of competition for the use of the land resources even in rural areas. Forests have to afford recreation and produce water as well as timber; farmers are beginning to have to accept restrictions on what they may do on their own properties, while good farmland is being lost to residential and industrial uses. Greater appreciation of the conservation and recreational value of natural areas, for which there are still great opportunities in Western Australia, is also an important factor (Department of Conservation and Environment 1981).

The change from a pioneering State, with its "one million acres of new farms a year" to one in which Crown land releases for agriculture have been restricted and forest clearing controlled, has taken place in just about one decade. The community has to accept that areas of land can no longer be devoted exclusively to single uses, and the constraints involved in this. But to do so the public generally needs a broad general understanding of the complex natural systems and their responses to management, and it is desirable for this to be brought about quickly. While the sort of understanding required is growing among engineers, foresters, agriculturalists and other professionals involved in natural resource management, it is uncommon among people generally. Perhaps we need an extension service for the purpose, as well as those already in existence, which tend to provide advice for single uses such as farming or private pine plantations. If this were established then an informed public opinion could have proper influence at the political level, since major land use decisions are made by the elected government of the day.

But understanding alone is hardly sufficient if not taken into account in an effective land use planning process which the rapidly growing competition for the land resources demands. I have already illustrated the general need to integrate through planning, the principal rural land uses of farming, forestry and water supply. The need is even more pressing in the hinterland of Perth, with its urban residential and industrial growth. For example, between Perth and Bunbury there are already four alumina refineries established or under construction which, in addition to their present site areas, and the 450 ha per annum to be mined, will require close to 50 ha of land each year for residue disposal when in full operation; aluminium smelting at one or more site is likely; other industrial developments are increasing and recreation villages and dormitory suburbs are spreading along the coast and around estuaries and inlets. These attractive bodies of water are also affected by agriculture on the coastal plain. Due to generous applications of fertiliser and of water in the irrigation areas, phosphate lost from the soils in drainage accumulates in the inlets, giving rise to eutrophication and growth of algae and phytoplankton (Hodgkin *et al.* 1981).

In these times of public concern for conservation, many land uses are seen as having adverse environmental effects—clearing of forest may lead to deterioration of water quality and salinisation of soils, industry and residential development can destroy natural areas, reduce open space available for public enjoyment, and produce effluents with the potential to cause atmospheric and groundwater pollution. Agriculture too has its adverse effects. However, such interactions can also be viewed in another way, i.e. as one form of land resource use adversely affecting the potential for others, including provision of conservation reserves and national parks. Thus environmental protection can and should be accommodated to a large extent as part of general land-use planning, rather than be left as an institutionalised after-thought achieved through present requirments for environmental impact statements and environmental review and management programmes.

Strategic planning for the allocation of land resources cannot take place only at the local level. Yet beyond the Perth Metropolitan Region there are no statutory provisions for planning or zoning of land uses at the regional level. The absence of statutory regional land use planning over much of this area does not mean, however, that there is no planning at all. There are something like 95 statutes, 12 government departments, and 20 authorities of various kinds besides local authorities, concerned with land use planning in south-western Australia (Hohnen 1976). While there is some degree of co-ordination by such agencies as the Town Planning Board, the Environmental Protection Authority and the Department of Resources Development, the situation is obviously complex and likely to contain inconsistencies, so that it can hardly be said to provide a proper framework of policy within which individuals as well as government and other agencies can conduct their business with some degree of certainty. An adequate system of land use planning would allocate resources and locate industries with due consideration for the technical factors involved in land resource management. Without it, our increasing understanding of soils and other natural resource systems is unlikely to be fully exploited.

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Late Eocene benthic Foraminiferida, south coast, Western Australia*

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Abstract

The Nanarup Limestone Member of the Werillup Formation (Plantagenet Group) consists of white friable calcarenite of Late Eocene age. It has yielded an abundant, diverse fauna of benthic foraminifers which are discussed in this paper. The following new species are described: *Haplophragmoides regularis, Textularia nanarupensis, T. colemani, T. jutsoni, Gaudryina aculeata, Palmula hodgsoni, Quasibolivinella taylori* n. gen., n. sp., *Vaginulina hornibrooki, Pseudopolymorphina carteri, Buliminella rutledgei, Angulogerina hunti, Epistominella macgowrani, Globorosalina westraliensis* n. gen., n. sp., *Vernonina dorreeni, Linderina glaessneri, Gavelinella westraliensis.* Many of these new forms are well known in Late Eocene faunas across southern Australia but have not been described formally previously. Several other species are discussed and many recorded in Appendix 1. The Nanarup Limestone Member accumulated in warm, clear, fully marine conditions on the eastern (lee) side of a granitic island in water some 20-35 m deep. The fauna is representative of a Late Eocene faunal subprovince along the south coast of Australia.

Introduction

Friable white calcarenite occurs at Nanarup, near Albany (Fig. 1) and contains a rich assemblage of planktic and benthic foraminifers. The limestone is the Nanarup Limestone Member of the Werillup Formation within the Plantagenet Group. It outcrops in a quarry (Fig. 1) and the thickness and extent of the calcarenite are unknown but both are quite small. Quarrying has disturbed the material a great deal but specimens representative of the original lithology are quite abundant. One provided the fauna described here.

The fauna examined consists of 25 000 foraminifers of which 10% are planktic (see Quilty 1969). Noteworthy features of the fauna include the dominance by *Maslinella chapmani* Glaessner and Wade (about 30% of the benthic fauna) and the diversity and abundance of textulariid fauna, most of which is made up of previously undescribed species.

Quilty (1969) and Clarke and Phillips (1954) have given summaries of early work on the Tertiary of the region. The following are the most important references bearing on this study. Jutson and Simpson (1916) named the Plantagenet Beds and recorded *Aturia australis* McCoy. Chapman and Crespin (1926) placed the Plantagenet Beds in the Middle Miocene on molluscan evidence but later (1934), with further study, they considered them to be Early Miocene. Crespin (in Clarke, Teichert and McWhae 1946) replaced them in the Middle Miocene.

Glaessner (1953) seems to have been the first to dispute the Miocene age when he considered the age to be Late Eocene on the basis of *Aturia clarkei* Teichert, elsewhere of this age. Glenister and Glover

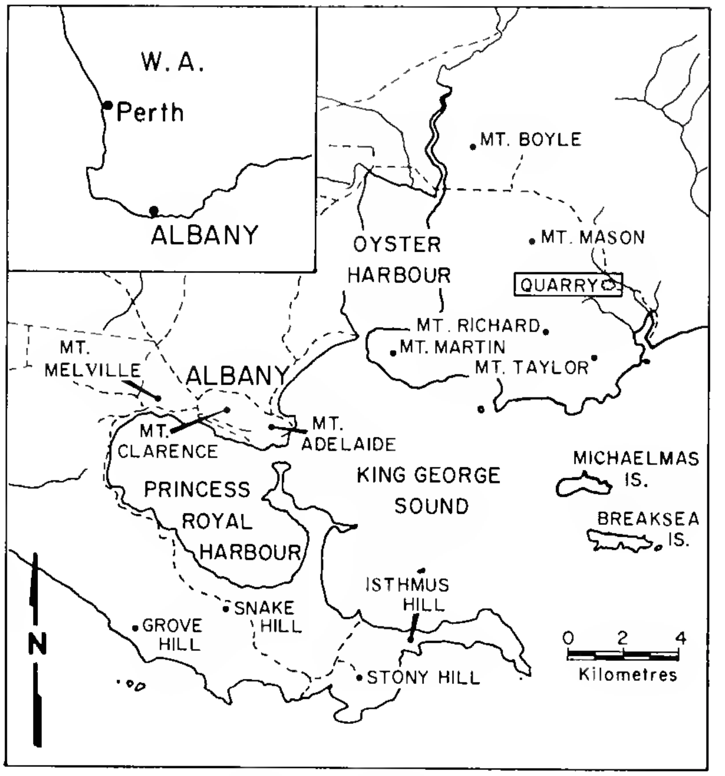

Figure 1.—Locality map.

* Appendix 1 is a Supplementary Publication and is not printed with the paper. Copies are lodged with the Society's Library (c/o Western Australian Museum, Perth, W.A. 6000) and with the National Library of Australia (Manuscript Section, Parkes Place, Barton, A.C.T. 2600) and photocopies may be obtained from either institution upon payment of a fee.

(1958) also gave a Late Eocene age because of the presence of *Deltoidonautilus prora* (Glenister, Miller and Furnish) a characteristic Late Eocene nautiloid. McWhae *et al.*, (1958) and Glaessner (in Lotze 1959) also quoted a Late Eocene age, probably on the basis of the nautiloid. McTavish (1966) was the first to publish the name Nannarup (sic) Limestone in discussing correlation of the Solomon Islands Tertiary. This reference was to very early work of the author (Quilty in Hodgson, Quilty and Rutledge 1961). Cockbain (1967) recorded *Asterocyclina* from near Esperance and in 1968 (c) clarified the terminology of the sediments, erected the Plantagenet Group and defined several new formations, including the Werillup Formation of which the Nanarup Limestone (source of the material studied here) is a member. Also in 1968 (a, b), he recorded the nautiloid *Cimomia* and some foraminifers from Norseman. In 1969 he reported dasycladacean algae from the Werillup Formation near Esperance. He has recorded *Cyclammina* from elsewhere in the Plantagenet Group (Cockbain 1974). Backhouse (1970) listed the faunas from equivalents of the Nanarup Limestone Member at Esperance and included many of the forms described here. Quilty (1969) detailed the planktic foraminifer fauna from the Nanarup Limestone Member, documenting a Late Eocene age. In 1970 he described the problematical *Triangulina inflata* from these sediments and later (Quilty 1975) described *Schackoinella wadeae* from the same locality. The relationships of these sediments and faunas are discussed briefly in Quilty (1974 a, b). Hos (1975) recorded palynomorphs also from near Albany and confirmed the Late Eocene age. Cockbain (1978) examined discocyclinid foraminifers from Western Australia and documented *Asterocyclina* cf. *hornibrooki* and *Discocyclina* sp. from the Werillup Formation near Esperance.

Faunal affinities

Some groups of benthic foraminifers are very useful for delineating faunal affinities and eventually for defining faunal provisions and realms. Some are not. Thus many species such as the various forms of *Rosalina* and many nodosariids are known worldwide and are as yet of little use in this regard. Other genera and species, including many in this fauna, are much more restricted in their distribution. The distribution of more restricted forms is controlled in part by climate and continental configuration, the latter controlling migration paths. Deposition at Nanarup occurred only some 10-15 m.y. after the separation of Australia and Antarctica began (Weissel and Hayes 1972) and this history has had an effect on the water circulation patterns at the time.

The break between Australia and Antarctica began as rifting much earlier (perhaps in the Jurassic) and by the Late Cretaceous a gulf (or even open waterway) had been opened, at least in the west (Quilty 1973, 1974; Johnstone *et al.* 1973). By the Late Eocene, New Zealand and Australia had drifted apart to their present relative positions (Hayes and Ringis 1973) and Australia and Antarctica must have been very much closer than they are now with Nanarup at some 65°S latitude (e.g. Crook and Belbin 1978). The similarity of the Australian and New Zealand faunas shows that there was free movement of shallow marine waters, probably from the west between Antarctica and Australia. Similar rocks and faunas may exist off Antarctica between present day longitudes of 110°E and 160°E. The scenario for this migration and water movement is very much in agreement with the model discussed by Frakes and Kemp (1972), Foster (1974), and Edwards (1975).

Another important control on sediment (and hence faunal) distribution is relative sea level. Quilty (1974, 1977, 1980) recognised four cycles of sedimentation in the Cenozoic of Western Australia. McGowran (1979) has extended the concept Australia-wide and defined the same cycles as Sequences. Within the Middle and Late Eocene, Quilty recognised two transgressions (Cycles 2A and B), which McGowran takes as one Sequence (his Sequence Two) but with the Late Eocene more widespread than the Middle. Within the Late Eocene (Quilty's Cycle 2B) he recognised three "excursions" and the Nanarup material is taken here to have been deposited during one of these "excursions" although it is impossible at present to say which one.

Within Quilty's Cycle 2B, warm water conditions prevailed with the temperature gradient (warm west, cooler east) discussed by McGowran, and noted here in connection with *Crespinina,* the presence of *Asterocyclina* in the west, and so on. It is not clear to which of McGowran's three peaks the *Asterocyclina* fauna belongs and there could be a slight age difference between the Esperance and Nanarup sediments and faunas.

There are strong endemic southern Australian and Australasian associations recognisable in this fauna and it seems that an Australasian faunal province existed in the Late Eocene and that three subprovinces can be recognized. One element of the Nanarup fauna, *Textularia magallanica* Todd and Kniker, is in common with the Late Eocene of Magallanes Province, Chile (Todd and Kniker 1952). Many of the new calcareous species described here are well known across southern Australia but apparently nowhere else. This group includes *Pseudopolymorphina carteri* n. sp., and *Crespinina kingscotensis* Wade. These species have been described or recorded by Glaessner and Wade (1959), Wade (1955), Crespin (1956), Ludbrook (1961), Lindsay (1969), Backhouse (1970), Lindsay and Bonnett (1973) and Cooper (1979). Another group of species (including *Quasibolivinella taylori* n. gen., n. sp. *Glabratella crassa* Dorreen, *Textularia ototara* Hornibrook, *Bolivina pontis* Finlay and several species of *Anomalinoides* and *Cibicides*) is in common with contemporary faunas of New Zealand, as may be *Asterocyclina hornibrooki* (Cockbain 1978).

Only few of the endemic species are known from the western margin of Australia even though rocks of the right age and facies seem to be present. An important exception is *Maslinella chapmani* Glaessner and Wade which was recorded (Glaessner and Wade 1959) from the Carnarvon Basin. This species is known also from aboriginal artifacts north of Perth (Glover and Cockbain 1971; Quilty 1978b). The distribution of Eocene rocks was summarised by Quilty (1974) and since then other Late Eocene faunas have been recorded from the Perth Basin (Quilty 1978a,b). The records of *Linderina brugesi* and *Victoriella plecte* in Condon *et al.* (1956) may refer

to *L. glaessneri* and *Wadella hamiltonenis*. If they do, this extends the area of occurrence of these forms. The other endemic species listed earlier are unknown from the western margin sections.

Thus it seems that foraminifer faunas from western and southern Australia and New Zealand represent a Late Eocene (Cycle 2B) faunal province which can be devided into three sub-provinces: (1) along the western margin and extending around the south coast approximately to Esperance and characterised by *Asterocyclina* (although this does not mean that all localities will yield *Asterocylina*); (2) along the southern margin between Western Australia and Victoria, overlapping with the first at its western end. It is characterised by the presence of a group of southern Australian-New Zealand forms including many described here, but lacking *Asterocyclina*. Some endemic forms are in common between this sub-province and the first; (3) New Zealand, consisting of the New Zealand Late Eocene, characterised, as is the first, by the presence of *Asterocyclina* and many endemic southern Australian-New Zealand forms. The ultimate control on the discrimination of subprovinces seems to be water temperature.

Local environment

Turbulence, salinity

The lack of sorting, presence of complete articulated brachiopods, echinoids and so on, suggest that current activity was negligible at the time of deposition of the sediment. This is further supported by the spatial distribution of the Nanarup Limestone Member which occurs in only a small area immediately to the east of present-day granitic hills which in the Eocene would have been granitic islands. The time-equivalent sediments outside the area are siltstone and spongolite, representing sedimentation of water-current borne detritus. The Nanarup Limestone Member accumulated in the lee of islands, protected from the easterly-moving current. The sediment accumulated under normal marine conditions as attested to by the foraminifers but also by the presence of nautiloids, abundant bryozoans etc.

Temperature

Asterocyclina (a warm water genus) occurs near Esperance, 600 km east of Albany (Cockbain 1967) and the Nanarup fauna includes rare keeled *Globorotalia* and a high diversity of planktic foraminifers. These occurrences, in a general way indicate water temperatures equal to or higher than the present values. In the Carnarvon Basin, 1 500 km to the north, abundant *Discocyclina* indicates tropical conditions. The decreasing proportion of subtropical or tropical indices farther east in southern Australia suggests that a gradient existed from the north-west to south-east of Australia with a tropical north-west and probably temperate south-east (see also McGowran 1979). The Albany-Esperance area was probably subtropical with water temperatures of approximately 18-25°C. Hos (1975) on the basis of palynology suggested that this region was subtropical or warmer and humid, totally consistent with the conclusions reached here.

Depth

The presence of a calcarenite made up of a very diverse fauna and flora, including abundant calcareous algae, suggests quite shallow deposition, but the absence of much abrasion on specimens and the lack of sorting suggests accumulation below wave base. The foraminifer fauna is composed of 10% planktic species, suggesting deposition in about 30 m water depth although this figure, based on a single sample, must be accepted very tentatively. Faunal dominance (Walton 1964) is 28% and faunal diversity 16. Thus the fauna can be attributed to a position close to the boundary between 0-20 and 20-40 fathom fields. Also noteworthy is the low bolivinid percentage, also consistent with deposition in less than 35 m water depth. Consequently, a depth of deposition of about 20-30 m seems reasonable. The palaeogeographic map (Fig. 2) has been made allowing for the fact that the present day altitude of the limestone is 20 m above sea level.

Systematic Palaeontology

The taxa discussed include (a) new species and previously-defined species on which some significant comment can be made and (b) specifically-unidentified forms worthy of comment; all these are figured. Other species are listed in Appendix 1; a few of the 108 species so listed are figured in this paper.

All specimens referred to in the text and figures are housed in the palaeontology collection of the Geology Department, University of Western Australia. In the figure captions they are preceded by the abbreviation U.W.A.G.D. but this has been omitted

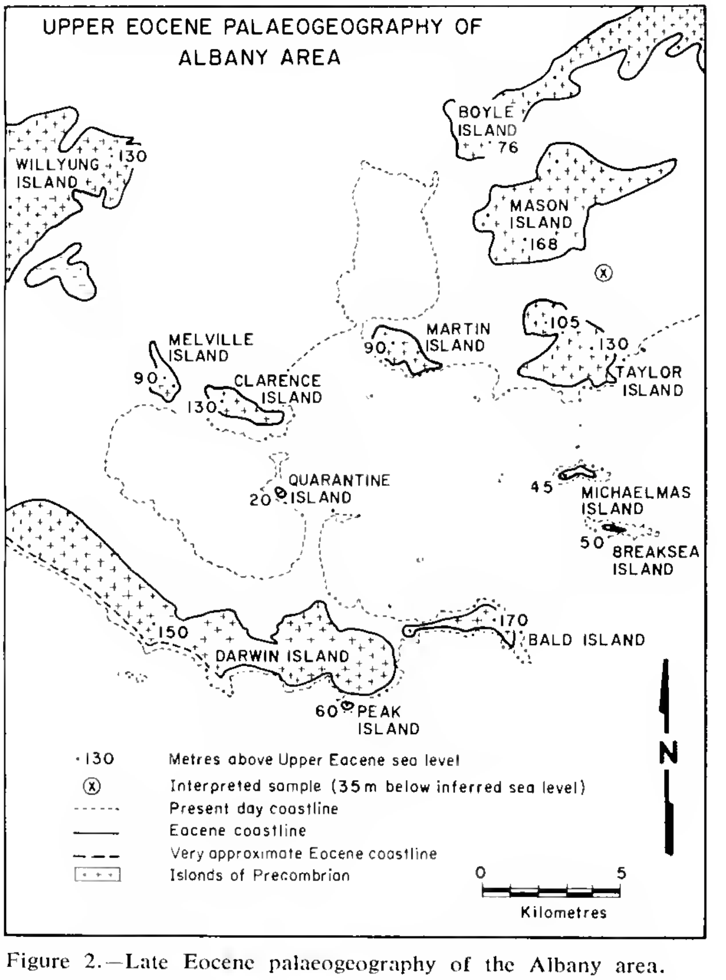

Figure 2.—Late Eocene palaeogeography of the Albany area.

from the text. All new species and many of the other forms have been measured for length, width and thickness and these have been plotted. Copies of these plots are available from the author.

Order Foraminiferida Eichwald 1830

Suborder Textulariina Delage and Herouard 1896

Superfamily Lituolacea de Blainville 1825

Family Hormosinidae Haeckel 1894

Genus **Reophax** de Montfort 1808

Reophax sp.

Figure 16G

Material: 2 specimens 59287-288.

Description and Remarks: Test finely arenaceous, slightly arcuate, circular in section; surface rough; sutures slightly depressed. Chambers 1½ times as wide as long. Aperture terminal, central, simple, situated on a short but distinct neck. Proloculus spherical, 0.4 mm in diameter. Only two specimens were recovered, one consisting of a proloculus and a second chamber, the other consisting of 3½ chambers with a well preserved aperture and neck. This undescribed species bears closest resemblance to *R. euneta* Jensen, a Holocene Australian species, *R. bohemicum* Perner, a large Czechoslovakian Cretaceous form and *R. subnodulosa* Grzybowski, a Late Eocene Polish form.

Family Lituolidae de Blainville 1875

Genus **Haplophragmoides** Cushman 1910

Haplophragmoides regularis Quilty n.sp.

Figures 13A-C

Material: 18 specimens. Holotype 59289; paratypes 59290-59295, 59601.

Diagnosis: Haplophragmoides characterised by its small size, smooth surface and sutures which are slightly convex anteriorly and without external expression. Final whorl with 6 to 8 chambers. The ratio maximum diameter/breadth/thickness is remarkably constant at 6/5/3.

Description: Test small (average maximum diameter 0.60 mm, range 0.30-1.30 mm) convolutely coiled and therefore without umbilici. Thickness average 0.30 mm; range 0.16-0.55 mm. Outside surface smooth and sutures not apparent. In balsam or refractive index oil, sutures become evident and are simple, slightly convex anteriorly but not sinuous. Septa generally made up of few radially elongate quarts grains so that septum thickness corresponds to quartz grain thickness. Wall dominated by agglutinated material, almost devoid of cement, not labyrinthic. Final whorl with 6 to 8 chambers. In a specimen 0.45 mm in maximum diameter, the thickness of the outer wall in the ultimate chamber is 0.10 mm. The anterior septum of the same chamber is approximately 0.04 mm thick. Aperture a narrow slit at base of terminal face of ultimate chamber; symmetrical, equatorial in position. Periphery rounded without a keel, but more sharply curved in the equatorial region than on the lateral parts of each chamber. The ratio maximum diameter/diameter perpendicular to maximum/thickness remains remarkably close to 6/5/3 throughout the sample studied.

Remarks: Little or no primary calcium carbonate and no clay are present in the species and no colouration due to iron compound, so it seems likely that a tectinous cement is present. Fifteen of the 18 specimens recovered were measured.

There has been some confusion regarding the genera *Cyclammina* and *Haplophragmoides* in the Australian Cainozoic and the former has been identified from the Plantagenet Group by Cockbain (1974). Taylor (1965) discussed the distribution of Australian *Cyclammina* and decided that all are *Haplophragmoides.* Ludbrook (1977) showed that most are true *Cyclammina* with primary labyrinthic walls and thus are clearly different from the species under discussion.

Family Textulariidae Ehrenberg 1838

No consistent nomenclature has developed for textulariid morphology and I propose the self-explanatory terminology shown in Figure 3.

Genus **Bolivinopsis** Yakovlev 1891

Bolivinopsis cf. **cubensis** (Cushman and Bermudez) 1937

Figures 4, 13D, E

cf. *Spiroplectoides cubensis* Cushman and Bermudez 1937, p. 13, pl. 1, figs. 44, 45.

cf. *Bolivinopsis cubensis* (Cushman and Bermudez); Finlay and Marwick 1940, p. 107.

Bolivinopsis crespinae Parr; Ludbrook 1961, p. 21.

Bolivinopsis cubensis (Cushman and Bermudez); Cooper 1979, pl. 19, fig. 8.

Material: 34 specimens. Figured specimens 59306 (2 specimens).

Remarks: About 17 or 18 specimens appear to have all the biserial portion preserved but it is hard to be certain of this. Figure 4 shows a plot of diameter of the planispiral portion of micro- and megalo/spheric forms.

Solution in weak acid shows the wall to be finely arenaceous with non-calcareous material in it. A thin section indicates that the wall is imperforate and made up of calcareous cement and probably calcareous as well as non-calcareous particles. The calcareous cement seems granular and imperforate. Acid treatment also shows that the wall is lined with a tectinous (?) membrane, to which adheres much of the arenaceous material.

Genus **Textularia** Ehrenberg 1838

Textularia nanarupensis Quilty n.sp.

Figures 13F-H

Material: 53 specimens (42 complete). Holotype 59307; paratypes 59308-59313.

Diagnosis: A finely arenaceous *Textularia*, thickest near the periphery, thinnest at the axial suture, rhomboid in transverse profile. Basal angle averages 30°.

Description: Test free, very finely arenaceous, compressed, biserial throughout. Wall simple, made up of very fine calcareous and non-calcareous particles, cemented with apparently imperforate non-oriented granular calcite. Test lined inside with a thin colourless organic membrane. When a specimen is dissolved in very weak acetic acid, much arenaceous material remains attached to this membrane. Test consists of approximately 20 chambers arranged biserially.

Breadth/height of chambers approximately 2/1 in mature chambers. Average length 0.51 mm; range 0.28-1.00 mm. Average thickness 0.24 mm; range 0.12-0.38 mm. Average width 0.33 mm; range 0.20-0.55 mm. Early chambers have normal axial shape, later passing through an inflated stage and usually in larger specimens, the last 2 or 3 chambers are strongly inflated. In transverse section the species is rhomboid with rounded corners. Test shape generally slightly convex in small specimens, trian-

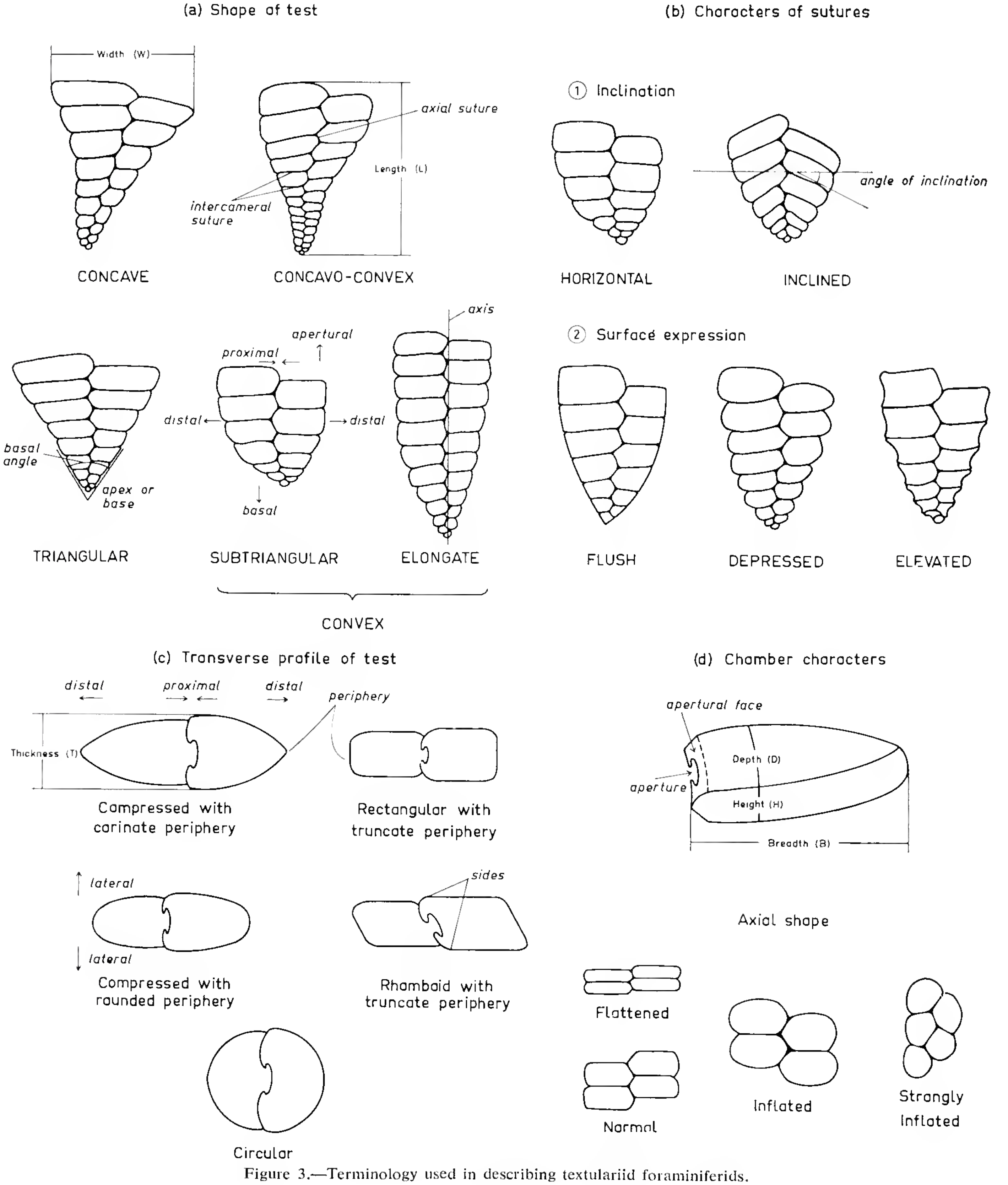

Figure 3.—Terminology used in describing textulariid foraminiferids.

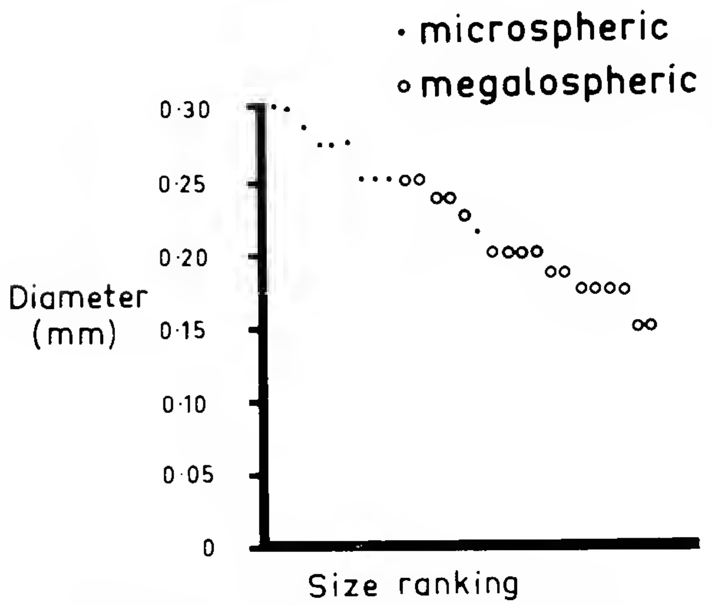

Figure 4.—Size ranking of *Bolivinopsis* cf. *cubensis* and its relationship to the microspheric/megalospheric generation alternation.

gular to concave in large specimens. Average basal angle 30°; range 20-40°. Test thickness least in the vicinity of the axial suture and greatest adjacent to the periphery, i.e. the sides are concave. The surface containing length and width often twists during growth. Sutures inclined, the angle of inclination averaging 38° (range 30-50°); depressed but much more strongly so in larger mature forms. Aperture simple, a slit near the proximal basal part of the final chamber; usually indistinct, but sometimes it is seen to be bounded by a well marked lip.

Remarks: When either length or width is plotted on a histogram, a slight bimodality is present, which may be due to the presence of both micro-and megalospheric specimens in the sample.

The closest described species to the new one appears to be *T. flintii* Cushman from the Holocene of the North Pacific, but the basal angle seems to be too large, and the test shape in that species is not rhomboid but truly rectangular. There is no marked general depression on the surface in the region of the axial suture and the sutures overall are too depressed to be the new species. Other similar species are found in the genus *Spiroplectammina*.

Textularia colemani Quilty n.sp.
Figures 13I-K

Material: 1430 specimens. Holotype 59314; paratypes 59315-59324.

Diagnosis: Textularia characterised by triangular outline, very white test made up mainly of fine calcareous particles and cement with flush sutures, average length 0.60 mm, width 0.54 mm and thickness 0.36 mm. Axial part of each side of the test has a zone of coarser arenaceous material.

Description: Test free, small, finely but obviously agglutinated; usually triangular in shape with an average basal angle of 50° and range 35-110°. Length range 0.20-1.12 mm; width 0.30-0.95 mm; thickness 0.20-0.60 mm. Surface of test smooth. Biserial throughout with 10-13 pairs of chambers. Periphery carinate, generally throughout ontogeny but occasional specimens have rounded periphery in the last 1 or 2 chambers. Walls thin with a tectinous inner lining. Arenaceous particles apparently mainly calcareous. Most of the non-calcareous residue after acid treatment remains attached to the tectinous inner lining. Along the axial part of each side of the test, there is a zone of coarser arenaceous material. Sutures generally flush and indistinct, but occasionally slightly depressed; not inclined except in the first few chambers. Axial shape of chambers changes quickly after 5 to 8 pairs of chambers (usually 6 or 7) have been formed. It changes from a flattened to normal shape, usually without having any effect on the overall test shape, but occasionally causing a small 'shoulder' to develop on the periphery. Aperture a narrow slit at the basal part of the proximal margin of each chamber.

Remarks: This species is the most abundant of the agglutinated foraminifers in this sample. One hundred were selected at random and were measured for length, width and thickness.

Of the species described from the Australasian region, *T. semicarinata* Hornibrook is the most similar. The length/width measurements taken from his paper (Hornibrook 1961, pl. 1, figs. 2, 3) fall within the range of this species. There is a discrepancy between his description and figures, however, as he states in the description that the holotype is 1.05 mm long whereas from his figure it is only 0.62 mm long. In either case the length/width ratio matches. *T. colemani* can be distinguished from *T. semicarinata* by its less distinct sutures and fewer chambers.

T. aegyptica Said has the same length/width ratio and size range but fewer chambers, extremely coarse skeletal material and the chambers are arranged in a regular series rather than changing character quickly after the sixth pair of chambers has been added. Also the carinate periphery is not marked enough.

T. bartonana Lalicker is too thick with respect to the width and length, i.e. L/W is too high and W/T too high, the sutures are too distinct in the later chambers and too few chambers seem to be present.

T. blocki Hoeglund is much more variable, and the final few chambers are much too inflated.

Textularia magallanica Todd and Kniker 1952
Figures 13L-N

Textularia magallanica Todd and Kniker 1952, p. 7, pl. 1, figs. 20, 21.

Material: 70 specimens. Figured specimen 59332.

Remarks: Average length is 0.86 mm; range 0.45 to 1.38 mm. Width is 0.60 mm; range 0.40 to 0.85 mm. Thickness is 0.42 mm; range 0.37 to 0.65 mm. Of the species so far described, *T. colemani* n.sp. from this locality is similar in wall structure, composition and surface texture but differs in size and in the characters of the sutures which are distinctly and uniquely depressed in *T. magallanica*. This species seems to be the only element of the benthic fauna which can be identified positively as being in common with coeval South American deposits and adds a little support for the contention that an open marine waterway existed between south-western Australia and the Pacific Ocean at this time.

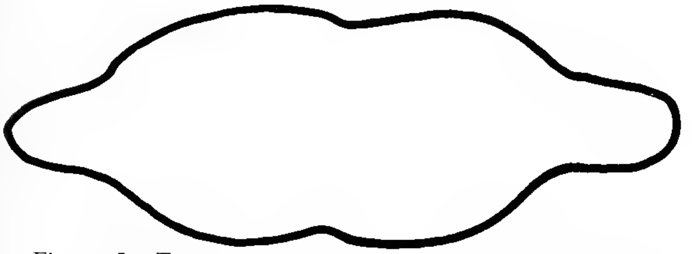

Figure 5.—Transverse profile of occasional specimens of *Textularia jutsoni* n. sp. with "pinched off" appearance.

Textularia jutsoni Quilty n.sp.
Figures 5, 13O-R

Material: 260 specimens. Holotype 59339; paratypes 59340-346, 59603.

Diagnosis: Textularia with variable sutural characters, fairly constant length/width/thickness ratio of 9/5/4 with periphery changing uniformly from carinate to rounded and chambers changing uniformly from flattened to inflated.

Description: Test free, biserial throughout, composed of particles of a wide variety of sizes. Most particles are small and obscured by cement but the surface has irregularly placed coarse particles in it, mostly quartz but with some calcite and occasional dark minerals. Average length 0.88 mm (range 0.45-2.6 mm); width 0.51 mm (0.25-1.0 mm); thickness 0.40 mm (0.17-0.85 mm). Shape elongate, subtriangular with a sharp apex. Thickest in the region of the axial suture. Periphery sharply carinate in early portion, becoming bluntly carinate and even rounded (in the last two chambers only) in large specimens. Early chambers usually with a simple compressed profile but occasional specimens are found with distal extremities which have a "pinched off" appearance, giving a transverse profile as in Figure 5. Surface of test generally fairly rough throughout, but occasionally smooth for the first few chambers. Sutural characters quite variable. Sutures generally flush and quite indistinct but sometimes quite sharply depressed in early stages. The specimens which have sharply depressed sutures are usually those with "pinched off" periphery. Angle of inclination of intercameral sutures usually 0-10° but sometimes directed away from the base distally. Chambers usually flattened in the early stages and changing slowly and uniformly to inflated in the last two chambers of large specimens. Length/width/thickness ratio quite constant at about 9/5/4. In later chambers at least, the wall of each chamber appears to consist of three layers. The inner and outer thin layers are dark in colour, probably due to a concentration of fine particles in them. The median layer is clearer and has obvious grains in it. The coarse material is concentrated in this layer but very coarse particles transgress all layers. Aperture situated at the base of the proximal face of each chamber, and varies from a low slit to a semicircular arch about 1/4-1/2 as wide as the test is thick.

Remarks: The few specimens of the species with "pinched off" peripheries and depressed sutures in the early stages resemble closely *T. marsdeni* Finlay, but the Western Australian species has irregularly scattered coarsely arenaceous particles in it whereas *T. marsdeni* is finely arenaceous (Finlay 1939, p. 90). The species is named in honour of J. T. Jutson, co-author of the name Plantagenet Beds.

Family Ataxophragmiidae Schwager 1877
Genus **Gaudryina** d'Orbigny 1839
Gaudryina aculeata Quilty n.sp.
Figure 13S

Material: 6 specimens. Holotype 59304, paratypes 59300-303.

Diagnosis: Small *Gaudryina* with basal angle 18-22°, 10-12 whorls in dominant triserial portion. Very reduced biserial portion.

Description: Test small, free, finely arenaceous, elongate with length/breadth ratio about 5/2, composed of a dominant basal triserial portion and a later very reduced biserial portion. Average length 0.55 mm (range 0.37-0.77 mm); breadth 0.25 mm (0.20-0.27 mm). Triserial portion of about 10-12 whorls with basal angle of 18-22°, making up 80-100% of test length. Sides of this portion flat or slightly concave, margins straight carinate. Sutures flush, invisible unless specimen immersed; almost perpendicular to test axis. Zigzag suture in centre of each face restricted to very narrow zone. Biserial portion short, of 2-3 whorls making up to 20% of test length. Half of recovered specimens have no biserial portion. Sutures in biserial portion a little depressed. Aperture basal in proximal margin of apertural face.

Remarks: The new species is described from six specimens of which one was lost after measurement. The most characteristic features of the new species are its low basal angle and the dominance of the triserial portion. The new species is similar to the triserial portion of *G. attenuata* Cushman (1913) but the latter has a dominant biserial portion, making up about 80% of the test length.

Suborder Rotaliina Delarge and Herouard 1896
Superfamily Nodosariacea Ehrenberg 1839
Family Nodosariidae Ehrenberg 1838
Genus **Dentalina** Risso 1826
Dentalina cf. **colei** Cushman and Dusenbury 1934
Figure 14A

cf. *Dentalina colei* Cushman and Dusenbury 1934, p. 54, pl. 17, figs. 10-12; Parr 1938, p. 76, pl. 1, fig. 8; Rau 1956, p. 73, pl. 14, figs 12, 17.

Material: 16 specimens. Figured specimen 59359.

Remarks: This is the largest nodosariid in the sample, ranging in size up to 4.2 mm and estimated up to 7-8 mm long. The species found here is doubtfully separable from *D. advena* Cushman, but the name *colei* is used for a distinctly larger, thicker-walled form than that referred to as *D. advena*. The specific name is regarded as tentative, since compressed early chambers were not seen. The species resembles very closely indeed what Rau (1956, pl. 14, fig. 12) figured as *D. colei*.

Dentalina sp. A.
Figure 16H

Material: One specimen 59352.

Description and Remarks: Two almost spherical chambers separated by a very deep suture perpendicular to the growth axis. Total length 0.7 mm and width 0.3 mm. The length/width ratio of the chamber is 7/6. Surface with about 25 longitudinal ridges which are not present in the suture. Apertural characters not visible. There seems to be a slight bend in the growth axis.

Dentalina sp. B.

Figure 16I

Material: One specimen 59355.

Description and Remarks: Specimen consists of two chambers. Sutures situated in shallowly, broadly depressed areas. Suture to suture length of the chambers is 6/5 times the width. Surface smooth; apertural characters not preserved. The specimen is 1.1 mm long and 0.4 mm wide.

Dentalina sp. C.

Figure 16J

Material: Four specimens; figured specimen 59356.

Description and Remarks: Specimens were not well enough preserved to allow positive identification. Test uniserial, arcuate, circular in section with a slightly eccentric, terminal, radiate aperture. Width and length equal in each chamber. Sutures perpendicular to growth axis and well marked. Test surface smooth. Proloculus wider than long. Length of figured specimen 1.9 mm.

As the specimen has a smooth surface and few very distinguishing characters, specific identification is very difficult. It bears some similarity to *Nodosaria radicula* Linné or *Nodosaria (Dentalina) soluta* Reuss as figured by Stache (Chapman 1926, pl. 3, figs. 19, 29).

Genus **Dentalinoides** Marie 1941

Dentalinoides sp.

Figures 16K,L

Material: Three specimens; figured specimen 59360.

Description: Test straight (?) with bilateral symmetry. Aperture terminal, a little eccentric, not radiate. Chambers 4/3 times as long as wide. Sutures clearly depressed but not greatly so, perpendicular to growth axis. Surface with 30-40 longitudinal ridges. More ridges occur in the median region of each chamber than at the sutures. The few extra ridges arise by intercalation.

Remarks: Two specimens consist only of two chambers, the other one of three. The specimens of two chambers are 1.0 x 0.5 mm and 0.9 x 0.45 mm respectively. What is present of the specimen here in consistent with Reuss' (1851) description of *Dentalina obliquestriata.* In his description he makes no statement about whether the aperture is radiate or not. Length of figured specimen 1.0 mm.

Genus **Lagena** Walker and Jacob 1798

Lagena sp.

Figure 16M

Material: One specimen 59373.

Description and Remarks: The specimen consists of a chamber 0.37 mm long and 0.40 mm wide surmounted at one pole by a neck 0.05 mm long and with a constant width of 0.10 mm. The neck has a series of "rings" on it, not expressed as annular ridges but seemingly a structure within the neck. The almost spherical chamber is pustulose with approximately 150-160 broad low domes scattered over the surface. No pattern of distribution is evident.

The pustules are small low domes. The "roof" of the dome is a thin layer of calcite (?) supported all round at its base by a stronger ring of skeletal material. The framework of the whole test is a series of ring structures. Maximum dimension of figured specimen 0.42 mm.

Genus **Vaginulinopsis** Silvestri 1904

Vaginulinopsis sp.

Figures 16P,Q

Material: Seven specimens; figured specimen 59404.

Description: Test elongate, somewhat compressed, with a tendency towards an arcuate habit. Test begins with a planispiral portion of 1/2—3/4 whorl which is carinate and of greater width than the rest of the test, followed by a uniserial portion of probably as many as four to five chambers. Side of test with the proloculus rounded; other side carinate. Chambers are less compressed and possibly narrower towards maturity. Sutures generally flush but slightly depressed in the later uniserial stages of some specimens. Sutures oblique by of the order of 75°-80° and sigmoid in shape. Aperture terminal, radiate, situated on the margin of the test opposite the initial coil.

Remarks: Six specimens have the initial coil complete, and only one has the uniserial portion complete. Average diameter of initial coil is 0.50 mm with a range from 0.40 to 0.55 mm. Average diameter of uniserial portion is 0.45 mm ranging between 0.35 and 0.50 mm. Thickness averages 0.30 mm with a range from 0.25 to 0.35 mm.

The species seems identical in lateral view with that figured by Chapman (1926, pl. 3, fig. 47.) as *Marginulina glabra* d'Orbigny, in plates which are reprints of Stache's (1864) plates. The figures show a species with a bulbous, noncarinate initial coil and therefore it cannot be this species. Chapman's and Stache's specimens are recorded from rocks of Early Oligocene age. Maximum diameter (length) of figured specimen 1.0 mm.

Genus **Palmula** Lea 1833

Palmula hodgsoni Quilty n.sp.

Figures 13 T,U

Material: 15 specimens. Holotype 59383, paratypes 59384-389.

Diagnosis: Palmula with an average length/width ratio of 2.15, apical and basal angles with an average value of 45°. Micro- and megalospheric forms quite distinct. Microspheric test with 13-15 chambers and proloculus 0.025-0.040 mm in diameter. Megalospheric test with an average of 8 chambers and proloculus diameter of 0.06 mm.

Description: Test free, rhombic in outline, very much compressed. Apical angle averages 45°, as does the basal angle. Length range 0.80 to 1.75 mm (megalospheric form reaches a maximum length of 1.4 mm). Width range 0.30 to 0.85 mm (maximum megalospheric width is 0.60 mm). Thickness of test 0.1 to 0.2 mm. Megalospheric proloculus is 0.06-0.12 mm in diameter and the two microspheric specimens have proloculus diameters of 0.027 and 0.040 mm. L/W ratio remains fairly constant at about 2-2.5. Megalospheric form consists on average of 8 chambers, of which the last 4 or 5 may be symmetrically developed, chevron-shaped. Intermediate series of chambers begins with a triangular deuteroconch followed by more elongate and

asymmetrically developed chevron chambers. Development follows the pattern of an evolute planispiral. Microspheric form consists of 13-15 chambers of which the last 10 or so are symmetrically developed chevron chambers. Aperture simple, terminal, situated in the centre of the chevron chamber.

Remarks: Of the 15 specimens recovered, only 9 are complete. The species is named in honour of E. A. Hodgson who was associated with me in our earlier work on the Plantagenet Group.

Genus **Quasibolivinella** Quilty n.gen.

Type species: *Quasibolivinella taylori* Quilty n.sp.

Generic diagnosis: Test compressed, flabelliform; chambers broad, low; sutures flush; aperture apparently basal. Initial chambers in the type species consist of a spherical proloculus surrounded by an annulus composed of two semicircular chambers. Growth thereafter usually biserial.

Remarks: The new genus clearly has very close affinity which *Bolivinella* Cushman, 1927. In *Bolivinella*, the proloculus is found at the proximal end of the test, is the most proximal chamber and is followed immediately by biserially arranged chambers. In the new genus this is not the case. In *Quasibolivinella*, the proloculus is at the proximal end of the test but it is not the end chamber of the test. The proloculus is surrounded, in the plane of the test, by an annulus consisting of two semicircular chambers, one of which is the chamber closest to the proximal end of the test (Fig. 6). These semicircular chambers may be the last phylogenetic vestige of a coiled ancestor. The presence of this vestige serves to distinguish *Bolivinella* and *Quasibolivinella*.

This genus has been recovered now from New Zealand by N. de B. Hornibrook and B. Hayward. The species there sporadically contains some forms with several uniserial final chambers (B. Hayward, pers. comm.).

Quasibolivinella taylori Quilty n.sp.

Figures 6-9, 13V,W

Bolivinella sp. nov. Crespin 1956, p. 37; Backhouse 1970, p. 41.

Gen. aff. *Bolivinella* Ludbrook 1961, p. 20, pl. 1, figs, 2, 3.

Gen. cf. *Bolivinella* Lindsay and Bonnett 1973, p. 19, pl. 2, figs. 6, 11.

Material: 615 specimens. Holotype 47514, paratypes 47515-517, 59600, 60602.

Diagnosis: *Quasibolivinella* with a length/width ratio of slightly less than 1, a median ridge and smooth sutures.

Description: Test free, biserial throughout, basically fan shaped but quite variable; compressed. Length 0.27-1.12 mm; width 0.27-1.20 mm. Proloculus spherical 0.1 mm in diameter, surrounded by an annulus of two semicircular chambers and followed by a biserial portion consisting of 1-12 pairs of chambers. Basal end often with a small spine. Chambers elongate and recurved quite markedly towards the end, often terminating distally in a small spine. Sutures between chambers on each side are flush and the test surface smooth. The central suture between chamber pairs varies from almost flush to quite a strong median ridge. The underlying suture zigzags but the ridge does not. The ridge is simple and not beaded. Apertural characters hard to define, but in the rare case where the aperture is seen, it is centrally situated, a slit at the base of the chamber, near the zigzag suture. (Fig. 7).

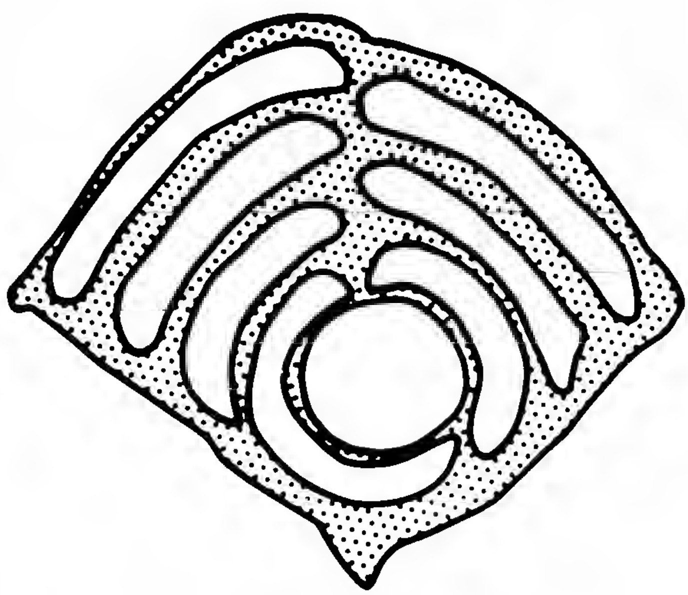

Figure 6.—Initial chambers of *Quasibolivinella* n.gen.

Remarks: Three hundred specimens are very well preserved, the rest being broken in part. Figure 8 illustrates the range in outline of the species. The size variation is shown in Figure 9.

The structure of the embryonic chambers appears unique. The proloculus seems larger in relation to the adult test than in *Bolivinella* which has a relatively minute proloculus.

The species description is based solely on Nanarup material but I have also seen what seems to be the same species from New Zealand, from studies presently being carried out by B. Hayward. This species seems to be restricted in southern Australia to rocks deposited in the time of Carter's Faunal Unit 2, such as in the Buccleuch Group A Beds in the Murray Basin, the Wilson Bluff Limestone of the Eucla Basin, and the Plantagenet Group. The species is named in honour of D. J. Taylor, in recognition of his work on the Australian Tertiary and Cretaceous foraminifers and stratigraphy.

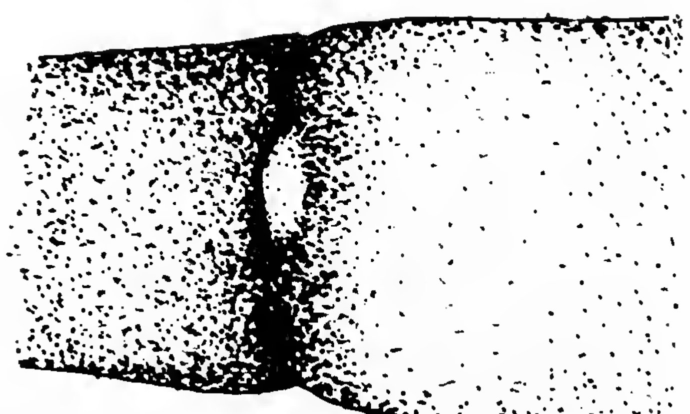

Figure 7.—The aperture of *Quasibolivinella taylori* n.gen., n.sp.

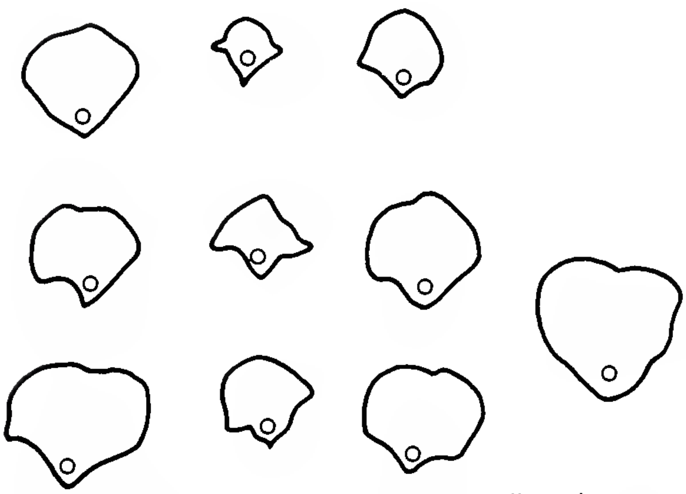

Figure 8.—Range of outline of *Quasibolivinella taylori* n.gen., n.sp.

Genus **Vaginulina** d'Orbigny 1826

Vaginulina hornibrooki Quilty n.sp.

Figures 14B,C

Material: 16 specimens. Holotype 59395, paratypes 59396-59400.

Diagnosis: Vaginulina with flush sutures, smooth surface, very uniform thickness, non-carinate margins and large proloculus.

Description: Test free, elongate, bilaterally symmetrical, oval in section, with flush sutures and smooth surface, composed of a large proloculus (0.30-0.45 mm), followed by a series of 6-10 chambers increasing uniformly in size. Length 1.1 to more than 2.5 mm; width 0.5-0.7 mm; thickness 0.35-0.50 mm. Test thickness remains very constant from proloculus to ultimate chamber. Margins not carinate. Test slightly arcuate with a terminal, radiate aperture situated at the end of the concave side. Sutures oblique to the growth axis by about 60° in later chambers, almost perpendicular in first one or two chambers, and only a little sigmoid. Chambers 2-3 times as wide as long.

Remarks: Of the specimens recovered, only two or three immature specimens are complete. Similar species to the new one include *Vaginulina sublegumen* Parr, which has a much slower rate of increase of width, and more chambers in the embryonic part. Several species from New Zealand (e.g. *V. awamoana* Hornibrook and *Marginulinopsis hydropica* Hornibrook) are similar but have a well-defined initial coil or depressed or elevated sutures. *V. alazanensis* Nuttall is different from the new species in being very nearly circular in section and in being relatively not as wide. The species is named in honour of N. de B. Hornibrook whose works have been so useful during this study.

Family Polymorphinidae d'Orbigny 1839

Genus **Pseudopolymorphina** Cushman and Ozawa 1928

Pseudopolymorphina carteri Quilty n.sp.

Figures 14D,E

Pseudopolymorphina sp. nov. Ludbrook 1961, p. 20 (Table 11), pl. 1, fig. 1.

Pseudopolymorphina sp. Lindsay 1969, p. 32, pl. 2, fig. 8; Backhouse 1970, p. 41; Lindsay and Bonnett 1973, p. 20, pl. 2, fig. 19; Cooper 1979, pl. 20, fig. 8.

Material: 28 specimens from this sample; 12 from others. Holotype 47504, paratypes 47505-507, 59421.

Diagnosis: Pseudopolymorphina with 5-9 inflated chambers with 30-50 fine longitudinal striae per chamber and strongly depressed sutures. First 3 chambers usually quinqueloculine, later chambers biserial.

Description: Test free, elongate, with 5-9 chambers, normally not more than 7 sometimes biserial throughout, but usually with first 3 chambers forming part of a quinqueloculine series, later developing a biserial habit, occasionally ending with 1 or 2 uniserial chambers. Usually 2-4, occasionally as many as 6 chambers arranged biserially. Average length 1.78 mm (range 0.6-2.7 mm); width 1.13 mm (0.40-1.25 mm). Length/width ratio of test, length/width ratio of individual chambers, amount of inflation of chambers, rate of increase of chamber size, all vary widely. Sutures clearly, broadly depressed, more so in later chambers. Part of preformed test thickened by a lamina of calcite with each new chamber added. Thickening most pronounced in sutural position, especially in early formed chambers. Thus early sutures are less pronounced than later ones. Chambers with a series of longitudinal striae, except in the surface immediately surrounding the aperture. Within a specimen, the number of striae increases with chamber size, but often relief becomes less until in some specimens, last chamber is smooth. Number of striae per chamber 30-50 but varies widely. In early chambers, striae commonly bifurcate and proceed continuously across sutures. In later chambers in the central inflated parts, short striae are intercalated between adjacent continuous striae. Aperture terminal, radiate.

Remarks: The new species is distinguished from most species of this genus by some combination of very inflated chambers, more distinctly depressed sutures and mainly in the characters of the striae. The closest species to the new one is *P. doanei* var. *beaumarisensis* Parr and Collins. In the new species

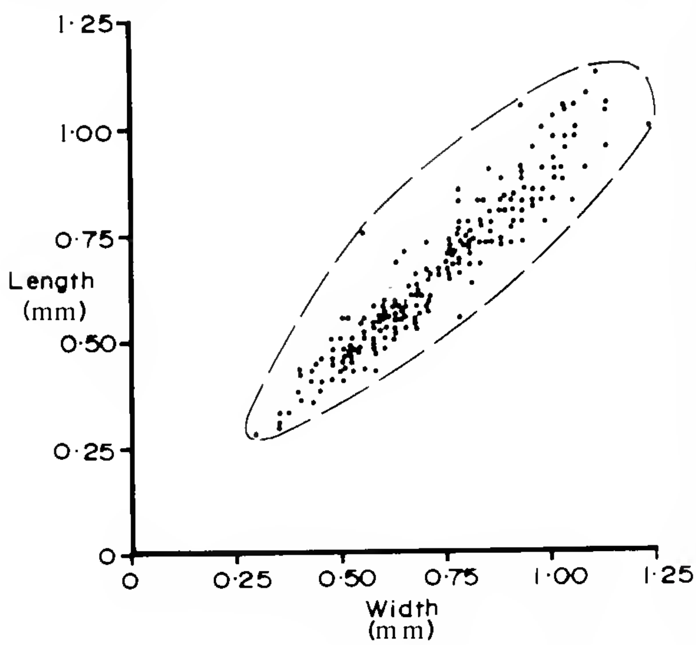

Figure 9.—Variation of length and width in *Quasibolivinella taylori*, n.gen., n.sp.

all the striae on a chamber are equally developed whereas in *P. d. beaumarisensis,* the striae may be of several different appearances. Usually they are less well-developed than on the new species. Other somewhat similar species such as *P. tasmanica* Parr and Collins and *P. victoriensis* Parr and Collins are not striate. As with *Quasibolivinella taylori* n. gen., n.sp., and *Linderina glaessneri* n.sp., *Pseudopolymorphina carteri* n.sp. is a well-known species characteristic of Carter's (1958) Faunal Unit 2 (Late Eocene). It has been figured by several authors but none have described it. The species is named in honour of A. N. Carter who has done a great deal to help develop new zonations of the south-eastern Australian Tertiary.

Superfamily Buliminacea Jones 1875

Family Turrilinidae Cushman 1927

Genus **Buliminella** Cushman 1911

Buliminella rutledgei Quilty n.sp.

Figure 14F

Material: 9 specimens. Holotype 59431; paratypes 59432-438.

Diagnosis: Buliminella with 20-40 ridges on its surface, oblique by about 5-10° to the test axis. Spiral sutures quite strongly depressed and the length/breadth ratio is just under 2/1. Nine to ten chambers in the final whorl.

Description: Test very roughly fusiform, consisting of a high trochospire of 3½-4½ whorls of chambers, 9-10 chambers in the last. Average length 0.65 mm (range 0.50-0.85 mm); width 0.35 mm (0.25-0.45 mm). Chambers broad, inclined at 55° to the axis of the test. Apical angle quite constant at about 50°. Intercameral sutures flush to slightly depressed. Spiral suture quite depressed throughout. Surface of test "decorated" with a series of fine ridges, at 5-10° to the axis of the test and thus not parallel to the individual chambers. The number of ridges is of the order of 20-40 in the middle part of the test. Ridges are quite oblique in the early part of the test but almost parallel in the mature test. Aperture basically the typical buliminid "comma-shape" but spathulate tooth plate all but fills the aperture. Margin of apertural face rounded.

Remarks: The closest described species to the new one appear to be *B. turbinata* (Terquem) and *B. seminuda* (Terquem). In the type figure and description of *B. turbinata* there are ridges present although Cushman and Parker (1947) state that the surface is smooth; however that species is much broader relative to length than is the new one and the ridges are consistently quite oblique to the test axis. The length/width ratio is higher than that of *B. seminuda* and the ridges are stronger and more continuous. Lindsay and Bonnett (1973) figured a species as *Buliminoides* sp. It is not possible from the figures to say whether or not it is *Buliminella rutledgei n.sp.* The species is named in honour of D. I. Rutledge, a co-worker on the Plantagenet Group.

Family Uvigerinidae Haeckel 1894

Genus **Angulogerina** Cushman 1927

The distinction between *Trifarina* Cushman, 1923 and *Angulogerina* Cushman, 1927, seems to be interpreted by Cushman and later workers as a variation in the proportion of the test which is triserial. In *Trifarina* this is generally a very small proportion and in *Angulogerina* a large portion. An examination of Ellis and Messina (1940 *et seq.*) shows that few species exist which can truly be called intermediate. Thus rather than use Loeblich and Tappan's (1964, p.C572) concept of *Trifarina,* I am regarding the two genera as valid and separate.

Angulogerina hunti Quilty n.sp.

Figures 14G,H

Material: 10 specimens. Holotype 59444; paratypes 59445-59453.

Diagnosis: Angulogerina with a length/width ratio of just less than 2; triserial portion with 3 well-marked carinae, one on each chamber and 8-9 other ridges on each chamber. Later uniserial chambers usually smooth.

Description: Test free, elongate with a length/width ratio very close to 2/1. Length 0.35-0.66 mm; width 0.20-0.30 mm. Test roughly triangular in section. First ¾-⅘ of test length made up of a triserial trochospiral part with a basal angle of 40-60°. After a few whorls the sides of the test are parallel. Test consists usually of about 3-4 whorls, possibly up to 6 in the microspheric form. All chambers have a series of 8-9 strong ridges on them, a central dominant one causing the triangular section of the test. The central ridge of each chamber joins the structure in the similar chamber of the succeeding whorl forming a carina down the test. The 3 carinae thus formed twist by 30-60° during growth of the test. The strength of the ridges decreases away from the base. Last 1-3 chambers arranged uniserially. These chambers are triangular in section, having an aperture with neck and phialine lip, and usually are smooth.

Remarks: The closest described species to the new one seem to be *A. cooperensis* Cushman, *A. angulosa* Williamson and *A. costornata* Hornibrook.

A. cooperensis, an Eocene species from the south-east United States, is very similar overall, but has too few ridges on it, probably too short a neck and its length/width ratio put it just outside the range of variation of the new species. *A. angulosa* is a present-day species and bears ridges on all chambers including the uniserial ones. It has much too high a length/width ratio and the three major carinae are too marked. *A. costornata* has the same length/width ratio, but the three major carinae are not marked enough. However, of all species, the last is closest. The species is named in honour of R. Hunt, part owner of the quarry at Nanarup.

Superfamily Discorbacea Ehrenberg 1838

Family Discorbidae Ehrenberg 1838

Genus **Epistominella** Husezima and Maruhasi 1944

Epistominella macgowrani Quilty n.sp.

Figures 14/I-L

Material: Two specimens from this sample; 23 from another. Holotype 59609; paratypes 59610-614.

Diagnosis: *Epistominella* with 2-2½ whorls, 6-7 chambers in the final whorl, test equally biconvex or with ventral side a little more convex. Dorsal surface always coarsely perforate and the ventral surface usually imperforate but on a few chambers is coarsely

perforate. Ventral umbilical boss quite well-developed. Maximum diameter/thickness ratio averages 1.84.

Description: Test free, lenticular, usually equally biconvex, but often ventral surface is a little more convex than the dorsal. Average diameter 0.51 mm (range 0.42-0.57 mm); thickness 0.27 mm (0.21-0.31 mm). Average diameter/thickness is 1.84 (range 1.67-2.2). Dorsal surface evolute, showing 2-2½ whorls with 6-7 chambers in the final whorl. About 16-20 chambers overall, normally about 9 in the penultimate whorl. Earlier chambers globular with straight intercameral sutures, these sutures, becoming more strongly recurved posteriorly distally, until in the last few chambers, the distal end of the anterior suture of any chamber terminates about 90° behind the proximal. All sutures flush, early parts of surfaces thickened. Dorsal surface smooth, coarsely perforate, the coarse pores being arranged in about four rows (in adult chambers), the rows being curved and parallel to the intercameral sutures; about eight to ten pores in each row. Ultimate chamber usually coarsely perforate but not always so. Proloculus diameter about 0.02-0.03 mm. Periphery with imperforate keel, not lobulate. Ventral surface smooth with central imperforate umbilical boss. Sutures flush, straight radial for proximal half, then recurved but not nearly as much as the dorsal side. Ventral wall generally imperforate, but sometimes one or two chambers are coarsely perforate. Ultimate chamber occupies about a 90° segment of this surface. Aperture mainly a low interiomarginal slit in the anterior suture, extending from the umbilical boss about 3/4 of the distance to the periphery, then with a short, posteriorly directed spur into the apertural face parallel to the periphery. Aperture enlarged very little by secondary resorption. Septa apparently monolamellid, wall structure radial, imperforate on the ventral side and the periphery, coarsely and regularly perforate on the dorsal. Pores are of the order of 0.01 mm across.

Remarks: It is named in honour of B. McGowran of the University of Adelaide.

Genus **Globorosalina** Quilty n.gen.

Type species: *Globorosalina westraliensis* Quilty n.sp.

Generic diagnosis: Test free, biconvex, a low trochospire. Wall radial lamellar calcite, coarsely perforate on the dorsal surface and on the peripheral parts of the final whorl; very finely perforate on the ventral surface. Test with coarsely pitted evolute dorsal surface. Ventral surface involute with stellate central area, rays of star formed by small umbilicus and incised proximal parts of intercameral sutures. Aperture umbilical, hidden beneath umbilical flap of each chamber. Secondary foramina developed in each apertural face when a new ultimate chamber is added. Secondary foramen not originally part of umbilical aperture, not in primary apertural face, but developed later and separated from primary aperture by a strong columnar buttress. Test probably has an axial canal (present in the type species) but without umbilical canal.

Discussion: The new genus bears a striking superficial likeness to *Rotalia* Lamarck, this likeness enhanced particularly by the ventral incised intercameral sutures. However, the new genus is distinct from *Rotalia* in having too few chambers in the final whorl (4-5 versus *Rotalia's* 8-17) and a coarsely pitted, coarsely perforate dorsal surface. The distinction is most marked when wall structure is examined.

The wall of *Globorosalina* is radial lamellar calcite not canaliculate as in the Rotaliacea. The septa appear monolamellar but as Loeblich and Tappan (1974) have shown, there is no significant difference between a monolamellar and a primarily bilamellar wall. Carter (1964, pl. 16, fig. 287) illustrated a section of *G. scabricula* which could be interpreted as having primarily bilamellar septa. *Globorosalina* is named for similarity to *Rosalina* to which it is closely related and from which it is distinguished by being very inflated, in having a rounded margin and in having a very thick wall. The new genus includes *G. westraliensis* n. sp. and *'Rotalia' scabricula* Chapman. The species described by Dorreen (1948 p. 297, pl. 39, figs. 6A-C) as *Lamarckina turgida* has many similarities with the new genus but the much larger basal aperture with pronounced lip and much more radially incised central ventral area serve to distinguish it from the new genus. *G. scabricula* (Chapman) was described in 1910 and has usually been referred to *Rotalia* Lamarck (e.g. Chapman 1910; Carter 1964). The two species referred to *Globorosalina* are only known from southern Australia.

Globorosalina westraliensis Quilty n.sp.
Figures 10,14M-R, 15A

Material: 37 specimens. Holotype 59486; paratypes 59487-59492.

Diagnosis: Test globular with average diameter/thickness ratio of 1.40 Dorsal sutures are clearly depressed; there is no discrete umbilical plug; the ventral intercameral sutures are deeply incised and bifurcate at the end of the incised part. Dorsal surface coarsely perforate. A large proportion of the ventral surface is finely perforate.

Description: Test free, globular, trochospiral, biconvex with a rounded periphery and average diameter/thickness ratio of 1.40. Average diameter 0.52 mm (range 0.47-0.75 mm); thickness 0.41 mm (0.30-0.56 mm). About 65% coiled sinistrally. Dorsal surface evolute, showing about 3 whorls with 5 chambers in the last whorl; surface very coarsely pitted. Spiral suture distinctly depressed and weakly lobulate. Intercameral sutures very vague and very weakly depressed, almost straight, directed strongly posteriorly distally. Periphery rounded, strongly pitted and coarsely perforate in the last whorl, but not in previous whorls. Periphery roughly circular in plan, weakly lobulate. Ventral surface convex, very involute without umbones or discrete umbilical depression. Ventral features are illustrated in Figure 10. Umbilical area marked by stellate pattern of incised proximal parts of each intercameral suture. Proximal 1/3—1/2 of each intercameral suture deeply incised. Distal end of each incised suture bifurcates for a very short distance. Intercameral sutures otherwise straight, radial, more or less flush.

Entire umbilical region imperforate or very finely perforate with smooth surface. Triangular areas between incised sutures are umbilical flaps of chambers. Aperture in the ultimate chamber a very low interiomarginal slit including the proximal 1/4 of the

proximal part of the apertural face, and either passing under the umbilical flap and into the proximal part of the posterior face of the chamber or terminating on the anterior face, another aperture opening into the posterior incised suture. Resorption is evident in the apertural face of the penultimate chamber. A low clear interiomarginal slit is now evident in the centre of the apertural face, distally removed from the primary aperture and separated from it by a thickened buttress. In the third last chamber, the secondary aperture has enlarged to take in most of the apertural face and form a very large, high arch separated from the still clear primary aperture by a much more thickened buttress. Buttress position coincides at the surface with the position of the bifurcation in incised sutures. Dorsal surface always very coarsely perforate; the peripheral part of the test coarsely perforate in the last whorl only. The rest of the wall and septa are finely perforate, composed of radially arranged lamellar calcite; very finely perforate when not coarsely so.

Remarks: It differs from *G. scabricula* (Chapman) in several features. It has distinctly depressed dorsal sutures. *G. scabricula* seems to have a discrete umbo or umbilical plug. This is absent from the new species. The incised sutures of *G. scabricula* are not bifurcate at their ends and extend from the umbilical area a relatively much greater distance distally. The imperforate or finely perforate central ventral area extends to the periphery in the adult in *G. scabricula*. *G. scabricula* is little more compressed with a ratio of about 1.75. Associated with this greater compression is a more angled periphery.

Genus **Vernonina** Puri 1957

Vernonina dorreeni Quilty n.sp.

Figures 15B-F

Material: 29 specimens. Holotype 59560; paratypes 59561-59566.

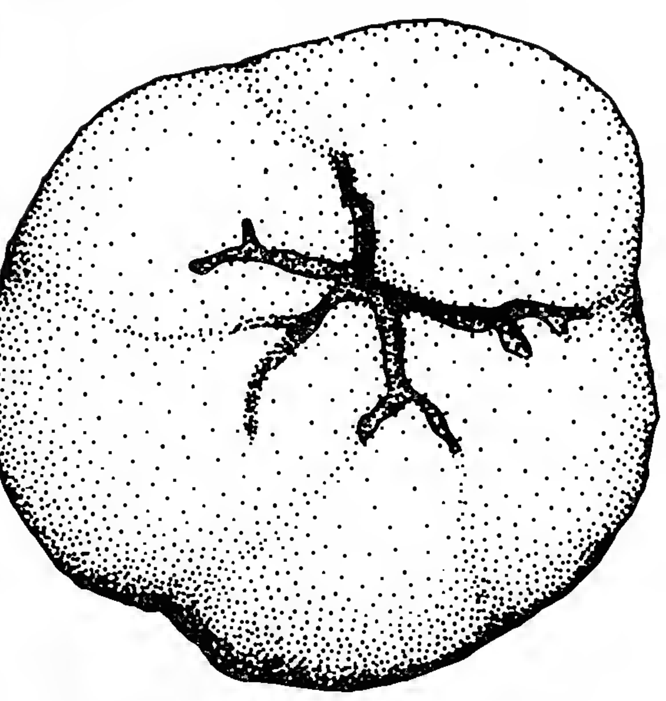

Figure 10.—Ventral face of *Globorosalina westraliensis* n.gen., n.sp., showing details of incised sutures.

Diagnosis: Vernonina with a uniformly, coarsely perforate, pustulose dorsal surface and a somewhat pustulose marginal part of the ventral surface; 6-7 chambers in the final whorl.

Description: Test free, small, trochospiral throughout, biconvex. One surface (generally the more evolute—here regarded as dorsal) much more convex than the other. Ventral surface a lower dome. Diameter/thickness ratio averages 1.6. Average diameter 0.53 mm (range 0.37-0.70 mm); thickness 0.33 mm (0.25-0.42 mm), Dorsal surface densely and coarsely pustulose without particular concentration of pustules. Dorsal intercameral and spiral sutures flush and not demarcated at all at the surface. Test of about 2 whorls with 6-7 chambers in the last. Dorsal sutures strongly recurved and rarely a little depressed. Periphery quite sharply keeled. Ventral surface a little convex, involute. This surface also often a little pustulose near the margins. Sutures usually flush, and straight radial to slightly recurved. Last chamber rather low and covering about 90° of the whorl on the ventral surface. Apertural face low and not steep. Apertural characters not seen on the last chamber, but, on broken specimens it is a low interiomarginal arch extending about 2/3 of the distance to the margin. At this position, the apertural face has a depression in it, extending from the distal end of the aperture, distally and ventrally away from the suture, and dying out very quickly. Septa apparently "monolamellar"; dorsal wall of lamellar calcite.

Remarks: Wall characters from thin section suggest that Loeblich and Tappan (1964) were correct in placing this genus in the Discorbidae. In the Australasian region, *V. dorsopustulatus* (Dorreen) is the closest known species to the new one, but has dorsal pustules only, and then only at the sutures, whereas in the new species, they are uniformly spread over the entire dorsal surface, and some are to be seen on the marginal part of the ventral surface. The new species is larger than *V. dorsopustulatus*.

V. dorreeni differs from *V. tuberculata* Puri in having consistently 6-7 chambers in the final whorl (rather than 7-8), a convex ventral surface, flush ventral sutures and non-pustulose ventral umbilical plug.

Family Planorbulinidae Schwager 1877

Genus **Linderina** Schlumberger 1893

Linderina glaessneri n.sp.

Figures 11, 15G-J

? *Eoannularia* sp. Crespin 1955, p. 49.

Gen. aff. *Linderina* Ludbrook 1961, p. 20.

Linderina sp. Lindsay and Bonnett 1973, pl. 2, fig. 12; Backhouse 1970, p. 41.

Material: 85 specimens. Holotype 47472; paratypes 47471, 47473-478, 59550-554.

Diagnosis: *Linderina* characterised by smooth surface, and with a very small protoconch (0.05 mm), very large and obvious deuteroconch (0.2 mm) surrounded by two half-whorls each of 3 chambers at each side of the deuteroconch.

Description: Test free, lenticular to discoidal with a maximum diameter/thickness ratio of 2.7 to 9; usually thin discoidal but often with an elevated central area on each side. Surface smooth, zone of equatorial chambers often undulatory. Test usually

circular in plan but often oval or a little irregular. Margin scalloped. Marginal equatorial chambers visible from outside, central ones covered by a laminated deposit of calcite. Average diameter 1.3 mm (range 0.4-2.45 mm); thickness 0.27 mm (0.15-0.45 mm).

Embryonic stage central. The protoconch is probably a small lenticular chamber (Figure 11) (1). This was probably followed by a large oval deuteroconch (2), 0.17-0.22 x 0.11-0.16 mm in size. One side of this deuteroconch has a much thicker wall (0.03-0.04 mm) than the other (0.007-0.02) and the protoconch is always on the thin walled side. Adjacent to the protoconch on either side are two pores, each of which probably leads into the first chamber of a half whorl of three chambers, the half-whorls coiling in opposite directions in a common planorbulinid fashion. Linking these two chambers (3) is a small chamber (4) probably formed from both chambers. From each (3) chamber, a half-whorl, 3, 5, 6 is formed and opposite the protoconch, in the centre of the thick walled side of the deuteroconch, the ends of the half-whorls are linked by another small chamber (7) which is very similar to 4. The details of chambers, 3, 5 and 6 are clear but the relationships of chambers 1, 2, 3 and 4 are not always so clear. The pores between 2 and 3 are visible in some sections but no pore between 1 and 2 was seen and in fact chamber 1 is not always seen. It is possible that chamber 4 forms before chamber 3 and gives rise to each half-whorl. The single aperture of chambers 5, 6 is inferred as are the dual apertures of 3 and 4. The arrangement is not always this exact, the half-whorls sometimes being irregular in that one may have only two chambers while the other may have four.

After the embryonic stage, chambers are added regularly in a series of 15-30 annuli, chambers of one annulus alternating regularly with those of the next with 20-25 chambers per annulus. For each annulus, a thin layer of radially arranged calcite is added to the entire test surface, so that a thick deposit of laminated calcite often builds up in the centre of the test. This lateral deposit is imperforate and contains many textural pillars. Pillars not randomly situated, but radiate in vertical section from the distal corners of each equatorial chamber. No aperture visible on the external part of the test at all. In equatorial section, all equatorial chambers have two apertures, one at each end, each leading into a chamber of the succeeding annulus. No specimens recognisable as microspheric were noted in the sample.

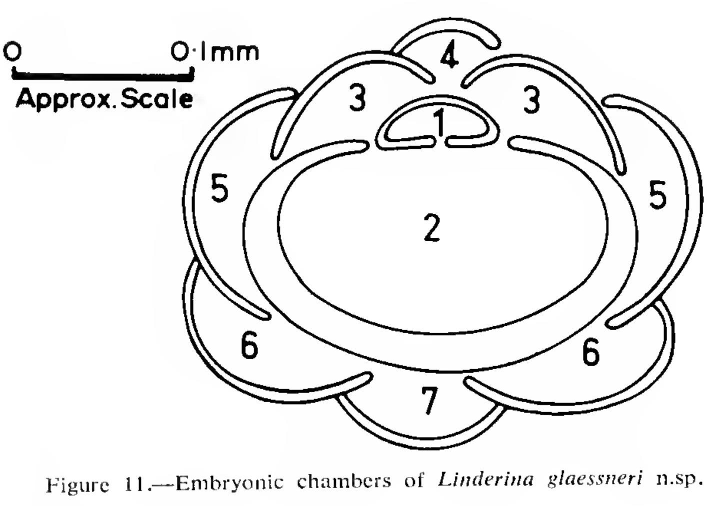

Figure 11.—Embryonic chambers of *Linderina glaessneri* n.sp.

Remarks: Of 85 specimens recovered, only 36 were preserved well enough for measurement with respect to maximum diameter and thickness. The main difference between this species and *L. brugesi* Schlumberger is in the embryonic stage. In this small species the deuteroconch is very much larger than the small lenticular protoconch, whereas in *L. brugesi* they are subequal. The difference in vertical section is not great although, in the new species, the deuteroconch is much larger relative to the rest of the test. It differs from *L. buranensis* Nuttall and Brighton in having a smooth surface, discrete chambers in each whorl instead of a continuous ribbon of calcite and a very large deuteroconch. This species appears to be another index fossil for Carter's (1958) Faunal Unit 2 of the Australian Tertiary. It is known now from the Buccleuch Group in South Australia (Ludbrook 1961) and from Upper Eocene rocks at Castle Cove and Johanna River south-western Victoria. It is named in honour of M. F. Glaessner, who has been one of the major forces in the study of Australian Tertiary foraminifers and stratigraphy for many years.

Family Acervulinidae Schultze 1854

Genus **Gypsina** Carter 1817

Gypsina disca Goes 1896

Figures 15R,S, 16A,B

Gypsina vesicularis (Parker and Jones) var. *disca* Goes 1896, p. 74, pl. 7, figs. 4-6.

Material: Seven specimens from this sample, 19 from others. Figured specimens 60597, 60599, 60600.

Remarks: The generic name is used here for a free or attached, regularly to irregularly organised form, discoidal to spherical, and differs from the diagnosis of Loeblich and Tappan (1964); *Sphaerogypsina* is thus included. The specific name *disca* is used although it is possible that the form could be *G. saipanensis* Hanzawa. The figures and description of that species are not adequate for detailed comparison. Although most specimens are the typical small discoidal morphotype, one specimen varies from the norm in being Y-shaped in vertical section and thus on one half of the specimen, there are two diverging equatorial surfaces.

Family Cymbaloporidae Cushman 1927

Genus **Halkyardia** Heron-Allen and Earland 1919

Halkyardia bartrumi Parr 1934

Figures 16C,D

Halkyardia bartrumi Parr 1934, p. 144, pl. 20, figs. 3-6; Finlay and Marwick 1940, p. 111; Cole 1954, p. 585; Hornibrook 1958, p. 29.

Halkyardia sp. Ludbrook 1961, p. 20, p. 1, fig. 5.

Material: Seven specimens. Figured specimens 59555, 59556.

Remarks: H. bartrumi, H. bikiniensis Cole and *H. minima* (Liebus) are very similar. The latter seems to have a central, ventral boss and thus may be distinct. In vertical section the chambers are more highly arched than in *H. bikiniensis,* and more like those of *H. bartrumi.*

Family Victoriellidae Chapman and Crespin 1930
Genus **Wadella** Srinivasan 1966
Wadella hamiltonensis (Glaessner and Wade) 1959
Figure 16E

Carpenteria hamiltonensis Glaessner and Wade 1959, p. 200, pl. 1, figs. 8-10, pl. 3, figs. 1, 2; Quilty 1961 *in* Hodgson, Quilty and Rutledge 1961, p. 40, pl. 3, figs. 4-6; Cooper 1979, pl. 21, fig. 3.

Wadella hamiltonensis (Glaessner and Wade) Srinivasan 1966, p. 249, pl. 4, fig. 13.

Material: Ten specimens. Figured specimen—59557.

Remarks: Glaessner and Wade (1959 p. 249) stated that *"Carpenteria" hamiltonensis, Victoriella conoidea* (Rutten) and *Eorupertia bermudezi* Anisgard are very similar. The species found here is distinct from *V. conoidea* in lacking very coarse bosses (it has much smaller ones consistent with *Carpenteria* or *Wadella*) and partly associated with this, it lacks the textural pillars of *V. conoidea. E. bermudezi* is separated by virtue of its smooth surface and imperforate lining. This may be the species referred by Cockbain (1967) to *Eorupertia* cf. *boninensis* (Yabe and Hanzawa).

Genus **Maslinella** Glaessner and Wade 1959
Maslinella chapmani Glaessner and Wade 1959
Figure 16F

Maslinella chapmani Glaessner and Wade 1959, p. 205, pl. 1, figs. 7, 8; pl. 3, figs. 4-8; Ludbrook 1961, p. 20, pl. 1, fig. 4; Quilty, *in* Hodgson, Quilty and Rutledge 1961, p. 43, pl. 3, figs. 6, 7; pl. 4, figs. 1, 2; Wade 1964, p. 274; Loeblich and Tappan 1964, p. C709, fig. 583; Backhouse 1970, p. 40; Glover and Cockbain 1971, p. 545; Quilty 1978b; Cooper, 1979, pl. 20, fig. 9.

Material: 6 500 specimens. Figured specimen 77919.

Remarks: This is by far the most numerous species in the fauna, making up 25%. Average diameter is 0.96 mm (range 0.45-1.95 mm). Average thickness is 0.45 mm (range 0.32-0.95 mm).

Plotting diameter/thickness data shows that this ratio is surprisingly regular when most morphological features, e.g. angularity of the periphery, degree of incision of sutures, are very variable. The form illustrated by Glaessner and Wade (1959 pl. 3, fig. 7) as microspheric, does not fit into the observed range of variation of the Nanarup fauna. It is relatively more thickened. As with occurrences elsewhere, with the exception of the possible Middle Eocene record in Lowry (1972, p. 122) this species occurs here in Late Eocene rocks and it seems to be a reliable index for Late Eocene (and possible Middle Eocene) in Australia. It is the only one of the apparently endemic southern Australian-New Zealand forms so far recorded also from the western margin of Australia.

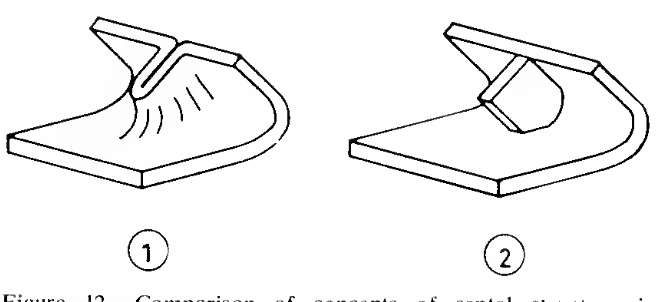

Figure 12.—Comparison of concepts of septal structure in *Crespinina kingscotensis* Wade. 1.—Wade's hypothesis. 2.—suggestion made here.

Superfamily Rotaliacea Ehrenberg 1839
Family Rotaliidae Ehrenberg 1839
Genus **Crespinina** Wade 1955
Crespinina kingscotensis Wade 1955
Figures 12,15Q

Crespinina kingscotensis Wade 1955, p. 45-59, pl. 8; Carter 1958, p. 15; Ludbrook 1961, p. 20; Lindsay and Bonnett 1973, p. 19, pl. 2, fig. 13.

Material: 18 specimens from this sample, 50 from elsewhere. Figured specimen 47485.

Remarks: Cone height and maximum diameter were measured on 68 specimens. Average maximum diameter is 1.72 mm (range 0.65-2.4 mm). Cone height averages 0.72 mm (range 0.27-0.8 mm). The ratio of maximum diameter/cone height for the sample is 2.39. Comparing the measurements here with those quoted by Wade (1955, p. 48), it is noticeable that there is a trend towards increase in size from east to west in this species. However, the trend to increased maximum diameter/cone height takes a sharp reversal.

Locality	Average maximum diameter (mm)	Maximum diameter/cone height
Castle Cove, Vic.	0.83	2.87
Johanna River—Browns Creek	0.92	2.87
Moorlands, S. Aust.	1.34	3.45
Kingscote, S. Aust.	1.48	3.39
Nanarup, W. Aust.	1.72	2.39

Interpretation of this trend is difficult. It could mean a general increase in water temperature from east to west—a not improbable hypothesis, as warm water species including *Asterocyclina* are known from rocks of this age 400 km east-north-east of here (Cockbain 1967) and also in north-west Western Australia. The total large foraminiferis fauna of Australia also suggests this trend (McGowran 1979). The envisaged gradient could well be similar to the present day case in which the water near Nanarup is consistently about 3C° warmer than the relevant eastern Australian localities (Defant 1961, pl. 3A, 3B).

A section cut parallel to one slope of the dorsal surface, and just below the dorsal surface, shows that the "septa" of the marginal zone do not appear to be simple infolding of the dorsal wall as suggested by Wade (1955 p. 46, text figure 1). Between the chamber walls and the end of each septum, there is a thin black line, probably representing organic matter deposited between the time of formation of the chamber wall and the "septum". Thus it appears that the "septa" are a later addition. (see Fig. 12).

Family Nummulitidae de Blainville 1825
Genus **Operculina** d'Orbigny 1826
Operculina budensis (Hantken) 1875
Figures 15O,P

Nummulites budensis Hantken 1875, p. 88, pl. 12, fig. 4.

Material: 16 specimens. Figured specimens 47502, 59618.

Remarks: Test complanate, smooth with maximum diameter/thickness ratio of 4-7 in larger specimens, 2.5-3 in specimens about 1 mm in diameter. Test of 2½-3 whorls, with 11-17 chambers in the final whorl. Protoconch 0.13-0.17 mm. Maximum diameter on

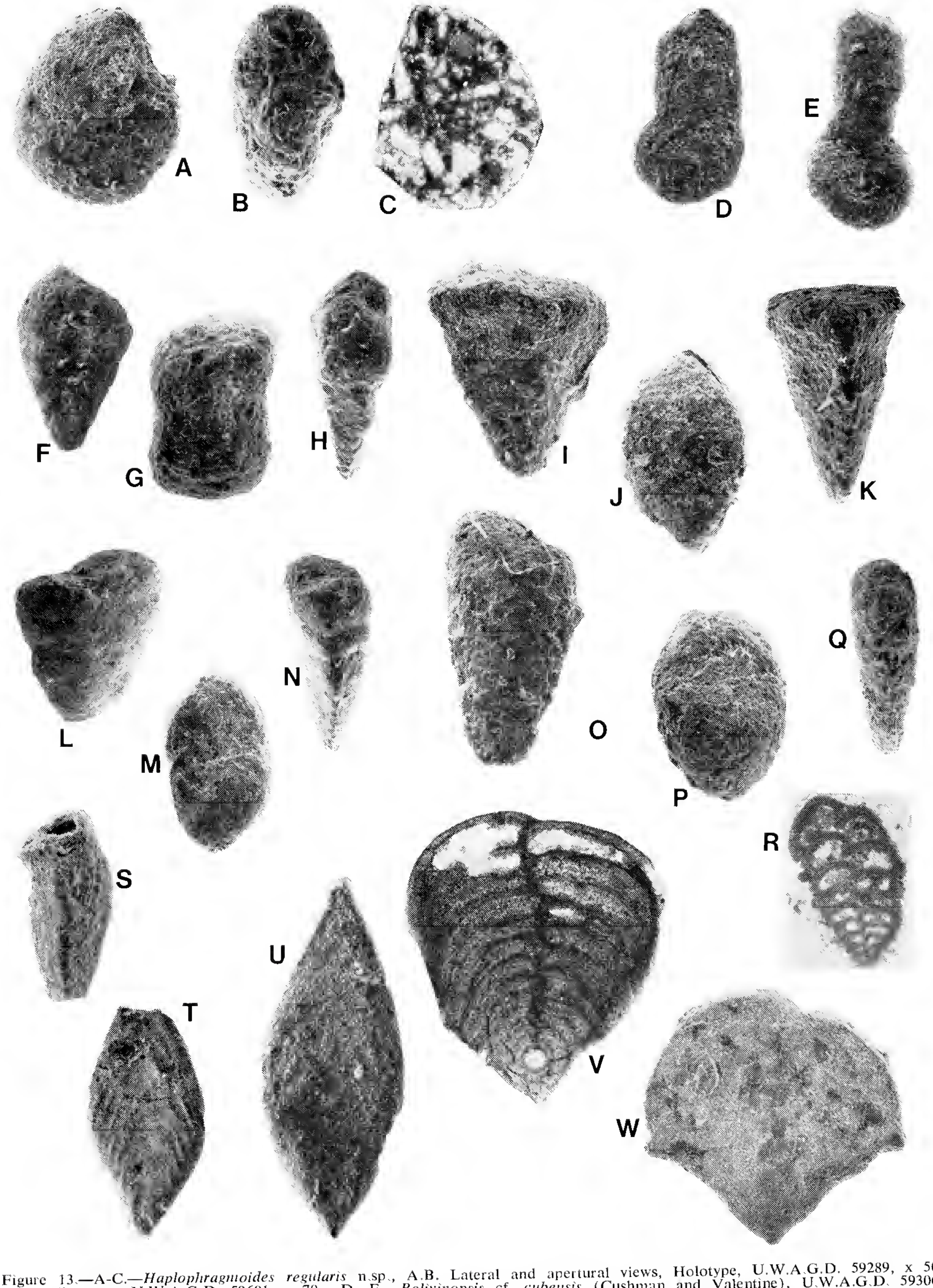

Figure 13.—A-C.—*Haplophragmoides regularis* n.sp., A,B. Lateral and apertural views, Holotype, U.W.A.G.D. 59289, x 50. C. Paratype U.W.A.G.D. 59601, x 70. D, E.—*Bolivinopsis* cf. *cubensis* (Cushman and Valentine), U.W.A.G.D. 59306, D. x 90, E. x 53. F-H.—*Textularia nanarupensis* n.sp., Holotype, U.W.A.G.D. 59307, F, H. x 40, G. x 70. I-K.—*Textularia colemani* n.sp., Holotype, U.W.A.G.D. 59314, I, K. x 55, J. x 60. L-N.—*Textularia magallanica* Todd and Kniker, U.W.A.G.D. 59332. L, N. x 35, M. x 40. O-R.—*Textularia jutsoni* n.sp, O-Q. Holotype, U.W.A.G.D. 59339, O. x 35, P. x 50, Q. x 25. R. Paratype, U.W.A.G.D. 59603, x 35. S.—*Gaudryina aculeata* n.sp., Holotype, U.W.A.G.D. 59304, x 60. T, U.—*Palmula hodgsoni* n.sp. T. Holotype, megalospheric, U.W.A.G.D. 59383, x 28. U. Paratype microspheric, U.W.A.G.D. 59387, x 33. V, W.—*Quasibolivinella taylori* n.gen., n.sp., V. Holotype, U.W.A.G.D. 47514, x 55. W. Paratype, U.W.A.G.D. 47515 x 70.

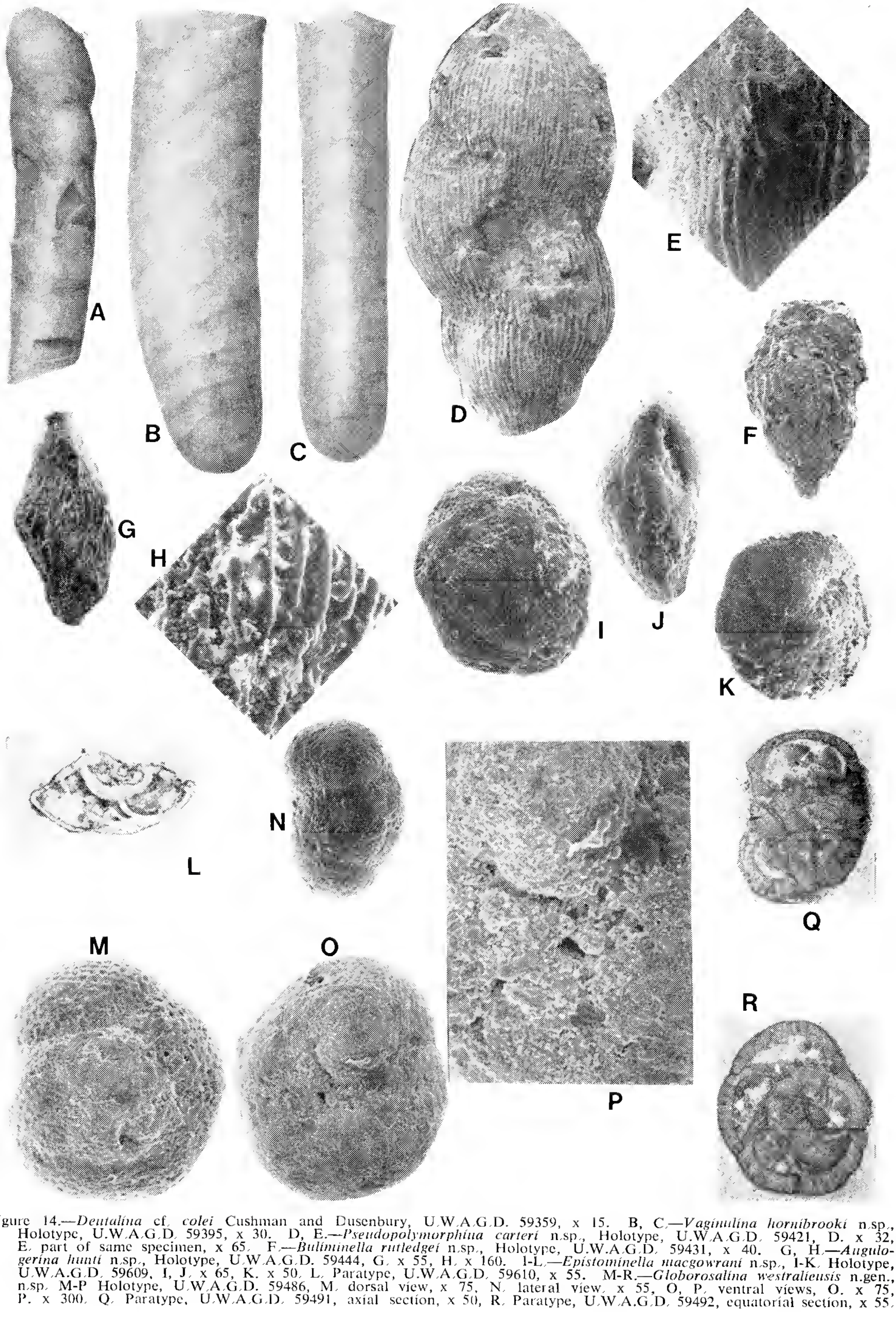

Figure 14.—*Dentalina* cf. *colei* Cushman and Dusenbury, U.W.A.G.D. 59359, x 15. B, C.—*Vaginulina hornibrooki* n.sp., Holotype, U.W.A.G.D. 59395, x 30. D, E.—*Pseudopolymorphina carteri* n.sp., Holotype, U.W.A.G.D. 59421, D. x 32, E. part of same specimen, x 65. F.—*Buliminella rutledgei* n.sp., Holotype, U.W.A.G.D. 59431, x 40. G, H.—*Angulogerina hunti* n.sp., Holotype, U.W.A.G.D. 59444, G. x 55, H. x 160. I-L.—*Epistominella macgowrani* n.sp., I-K. Holotype, U.W.A.G.D. 59609, I, J. x 65, K. x 50. L. Paratype, U.W.A.G.D. 59610, x 55. M-R.—*Globorosalina westraliensis* n.gen., n.sp. M-P Holotype, U.W.A.G.D. 59486, M. dorsal view, x 75, N. lateral view, x 55, O, P. ventral views, O. x 75, P. x 300. Q. Paratype, U.W.A.G.D. 59491, axial section, x 50, R. Paratype, U.W.A.G.D. 59492, equatorial section, x 55.

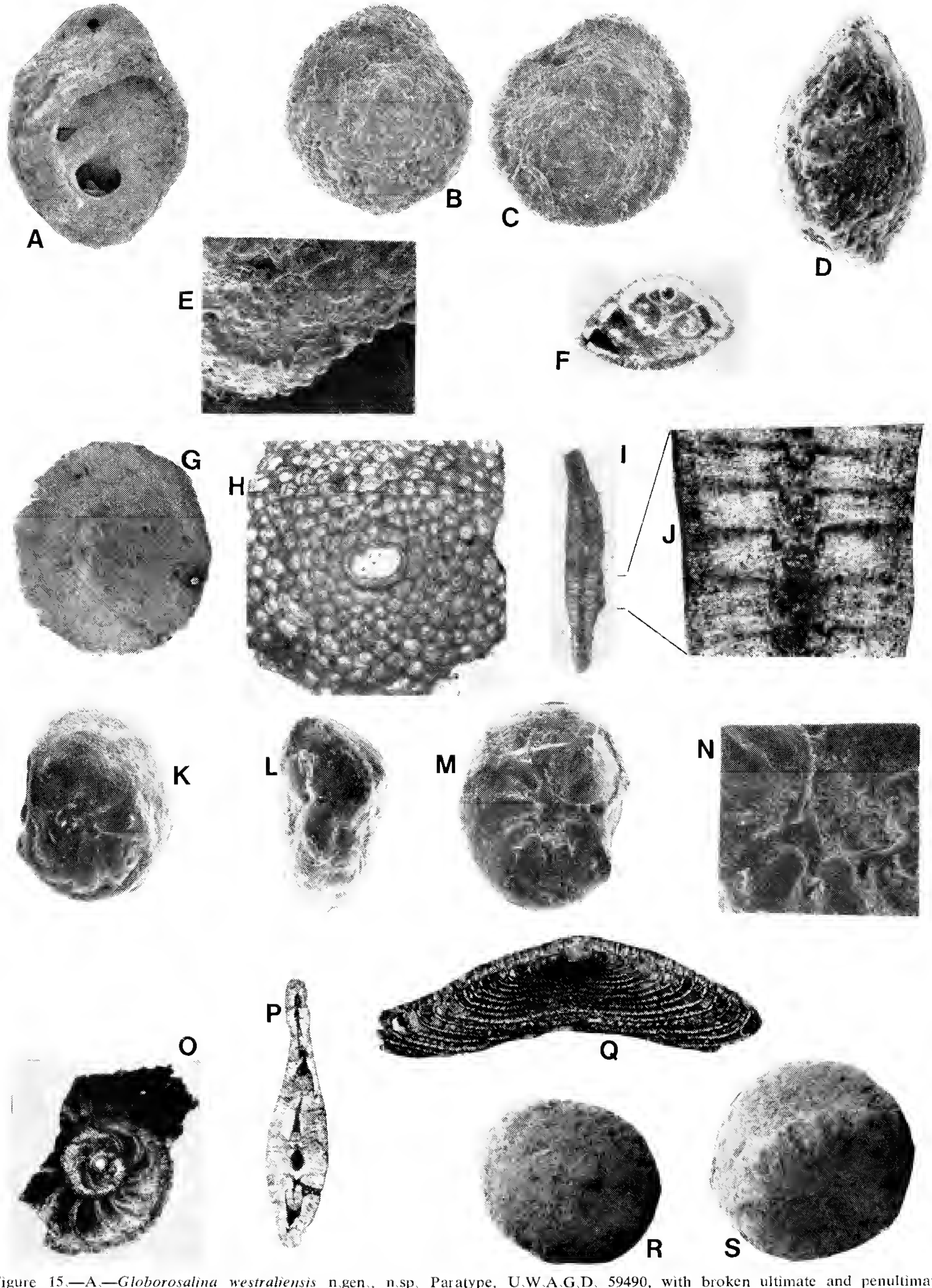

Figure 15.—A.—*Globorosalina westraliensis* n.gen., n.sp. Paratype, U.W.A.G.D. 59490, with broken ultimate and penultimate chambers showing resorbed chamber walls and thickened buttress, x 55. B-F.—*Vernonina dorreeni* n.sp., B-E Holotype, U.W.A.G.D. 59560, dorsal, ventral and lateral views, B, C. x 55, D. x 65, E. Enlarged view of lower right hand side of Fig. B, x 200. F. Paratype, U.W.A.G.D. 59566, Axial section, x 55. G-J.—*Linderina glaessneri* n.sp. G. Holotype, U.W.A.G.D. 47476, x 25, H. U.W.A.G.D. 47472, equatorial section, x 32, I, J. Paratype, U.W.A.G.D. 47471, axial section, I. x 17, J. x 120. K-N—*Gavelinella westraliensis* n.sp. Holotype, U.W.A.G.D. 59585, dorsal, lateral and ventral views, K-M x 50, N. Enlargement of ventral side, x 130. O-P.—*Operculina budensis* (Hantken), O. U.W.A.G.D. 47502, equatorial section, x 16, P. U.W.A.G.D. 59618, axial section, x 18. Q.—*Crespinina kingscotensis* Wade. U.W.A.G.D. 47485, axial section, x 40. R, S.—*Gypsina discа* Goes, R. U.W.A.G.D. 60597, normal discoidal specimen, x 16, S. U.W.A.G.D. 60598, abnormal specimen, Y-shaped in axial section, x 21.

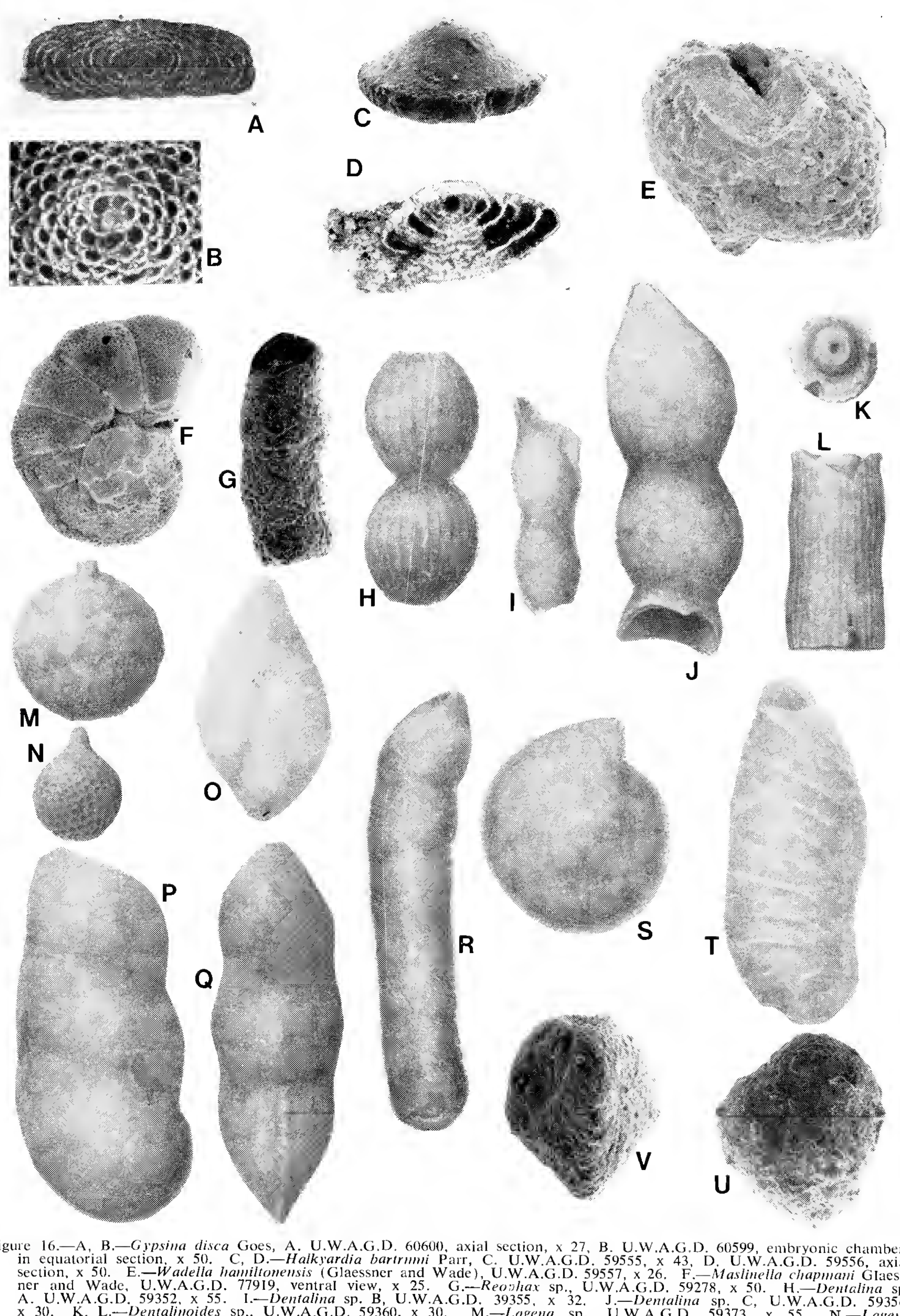

Figure 16.—A, B.—*Gypsina disca* Goes, A. U.W.A.G.D. 60600, axial section, x 27, B. U.W.A.G.D. 60599, embryonic chambers in equatorial section, x 50. C, D.—*Halkyardia bartrumi* Parr, C. U.W.A.G.D. 59555, x 43, D. U.W.A.G.D. 59556, axial section, x 50. E.—*Wadella hamiltonensis* (Glaessner and Wade), U.W.A.G.D. 59557, x 26. F.—*Maslinella chapmani* Glaessner and Wade, U.W.A.G.D. 77919, ventral view, x 25. G.—*Reophax* sp., U.W.A.G.D. 59278, x 50. H.—*Dentalina* sp. A. U.W.A.G.D. 59352, x 55. I.—*Dentalina* sp. B, U.W.A.G.D. 39355, x 32. J.—*Dentalina* sp. C, U.W.A.G.D. 59356, x 30. K, L.—*Dentalinoides* sp., U.W.A.G.D. 59360, x 30. M.—*Lagena* sp., U.W.A.G.D. 59373, x 55. N.—*Lagena hexagona* (Williamson), U.W.A.G.D. 59365, x 55. O.—*Guttulina communis* d'Orbigny, U.W.A.G.D. 59418, x 60. P-Q.—*Vaginulinopsis* sp., U.W.A.G.D. 59404, x 60. R.—*Dentalina advena* (Cushman), U.W.A.G.D. 59358, x 55. S.—*Lenticulina* cf. *rotulata* Lamarck, U.W.A.G.D. 59376, x 60. T.—*Vaginulinopsis marshalli* (Finlay), U.W.A.G.D. 59402, x 30. U.—*Dorothia parri* (Cushman), U.W.A.G.D. 59325, x 45. V.—*Reussella finlayi* Dorreen, U.W.A.G.D. 59442, x 65.

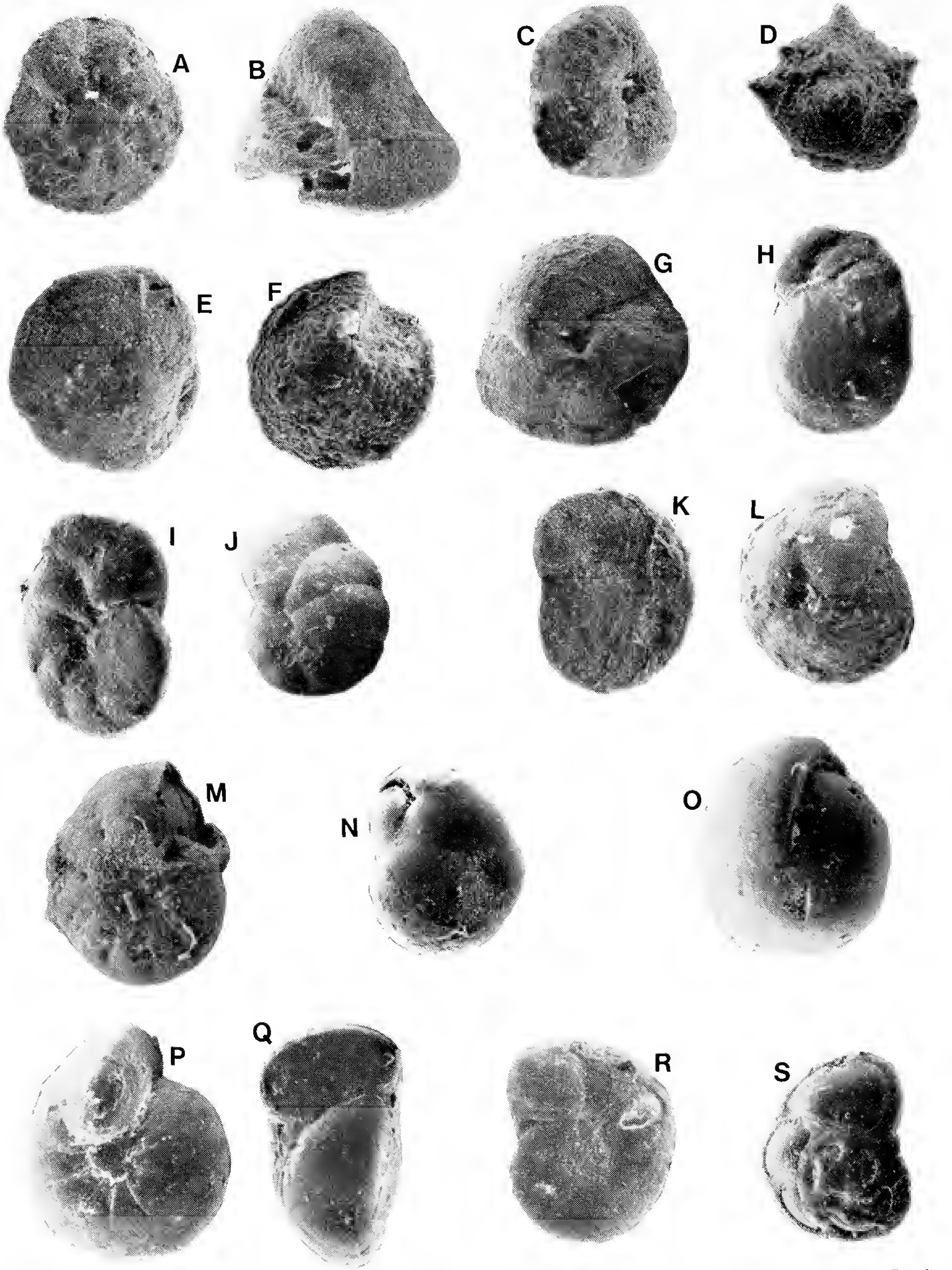

Figure 17.—A.—*Discorbis balcombensis* Chapman, Parr and Collins, U.W.A.G.D. 59455, ventral surface, x 45. B.—*Rosalina (Neoconorbina) turbinata* (Terquem), U.W.A.G.D. 59459, x 60. C.—*Glabratella crassa* Dorreen, U.W.A.G.D. 59470, x 55. D.—*Schackoinella wadeae* Quilty, Holotype, U.W.A.G.D. 59474, x 80. E.—*Asterigerina lornensis* Finlay, U.W.A.G.D. 59483, x 90. F.—*Cribrorotalia tainuia* (Dorreen), U.W.A.G.D. 59499, ventral surface x 45. G.—*Eponides lornensis* Finlay, U.W.A.G.D. 59567, ventral surface, x 40. H.—*Cibicides maculatus* (Stache), U.W.A.G.D. 59540, x 75. I, J.—*C. thiara* (Stache), U.W.A.G.D. 59543, I. x 50, J. x 42. K, L.—*C. vortex* Dorreen, U.W.A.G.D. 59542, x 75. M.—*Astrononion* cf. *parki* Hornibrook, U.W.A.G.D. 59576, x 110. N.—*Globocassidulina subglobosa* (Brady), U.W.A.G.D. 59570, x 60. O.—*Pullenia bulloides* (d'Orbigny), U.W.A.G.D. 59573, x 85. P, Q.—*Gyroidina zelaudica* Finlay, U.W.A.G.D. 59572, x 70. R.—*Anomalinoides macraglabrus* (Finlay), U.W.A.G.D. 59584, x 75. S.—*Mississippina concentrica* (Parker and Jones), U.W.A.G.D. 59594, x 35.

the 16 specimens seen is 0.6-2.6 mm with a mean of 1.5 mm. Thickness averages 0.4 mm with a range from 0.25-0.50 mm. Maximum diameter of figured specimens: 47502—2.00 mm; 59618—2.32 mm.

Superfamily Nonionacea Cushman 1927
Family Anomalinidae Cushman 1927
Genus **Gavelinella** Brotzen 1942
Gavelinella westraliensis Quilty n.sp.
Figures 15K-N

Material: 14 specimens. Holotype 59585; paratypes 59586-591.

Diagnosis: Gavelinella with average diameter/thickness ratio of 1.78, 7-8 chambers in the last whorl in large specimens, 9-10 in smaller specimens, and "umbilical" flaps on the ventral side which do not extend backwards over the previous suture. Umbilical area on ventral side characterised by star-shaped series of radial depressions.

Description: Test free, a very low trochospire, nearly plano-convex; more or less oval in cross section, bluntly carinate. Average diameter 0.48 mm (range 0.35-0.62 mm); thickness 0.27 mm (0.19-0.39 mm). Plane side almost completely involute and umbilicate. Central area surrounded by series of "umbilical" flaps from proximal parts of each chamber, giving central area a star-shaped series of radial depressions. Posterior part of each flap is part of opening of the aperture. This flap does not extend backwards over the preceding suture. Intercameral sutures clear, thickened, elevated above the rest of the test. Test surface otherwise smooth. Sutures and chambers straight and radial for the proximal 1/3 to 1/2 of proximal-distal height, then very strongly recurved. Chambers 7-8 in the last whorl in large specimens, but 9-10 in last whorl of smaller specimens. Periphery almost ventral, not lobulate, marked by dorsoperipheral slope which is concave in earlier chambers, almost plane in later chambers. In smaller specimens, this is less well developed. Convex (dorsal) side of test completely involute without deep umbilicus but with shallow umbilical depression. Depression simple and not "ornamented" with flaps etc. Sutures again elevated, thickened, initially straight radial and then recurved. Aperture a low interiomarginal slit, dominantly over the periphery and extending to the central area of the ventral side, but dying out before reaching the umbilical part of the dorsal side; bordered by lip or rim. After another chamber is added, the septum is considerably resorbed to form a large septal foramen a little to one side.

Remarks: G. zealandica Hornibrook is more compressed, has more chambers per whorl and has a younger stratigraphic range. The most similar species is *G. limbata* Olsson from which *G. westraliensis* is distinguished by having a less lobulate periphery even to the ultimate chamber, in having more markedly stellate ventral and dorsal umbilici and in having a very characteristic profile. The periphery is almost ventral and there is a sloping dorsoperipheral band which is distinctly concave in early chambers of the final whorl and almost flat in the ultimate chambers. *G. limbata* occurs in the Early Eocene. *G. westraliensis* differs from most other species in heing more robust and in being relatively thicker. The well marked stellate appearance of each surface is very characteristic.

Conclusions

1. Several species described and recorded here attest to the existence of an Australasian faunal province in the Late Eocene and that a "sub-province" may be recognised in southern Australia itself. 2. There must have existed a seaway between Australia and Antarctica to allow free migration of the Australian and New Zealand faunas. 3. There probably existed a temperature gradient from warmer waters in south-western Australia to cooler in south-eastern Australia. 4. The fauna described here accumulated in water 30 m deep or shallower, in warm clear conditions in the lee of an island.

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